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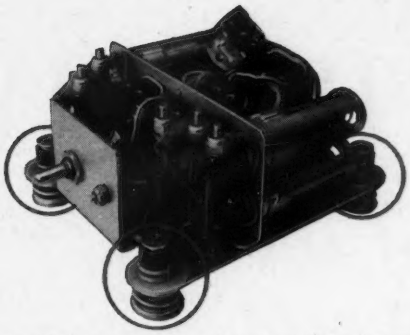

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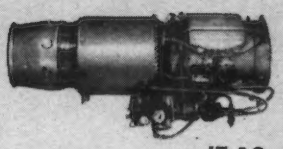

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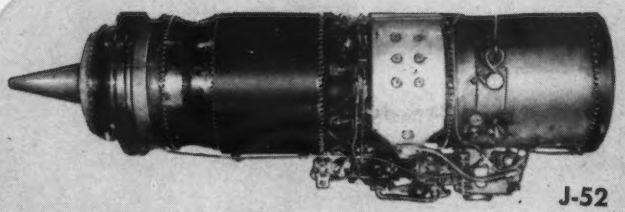

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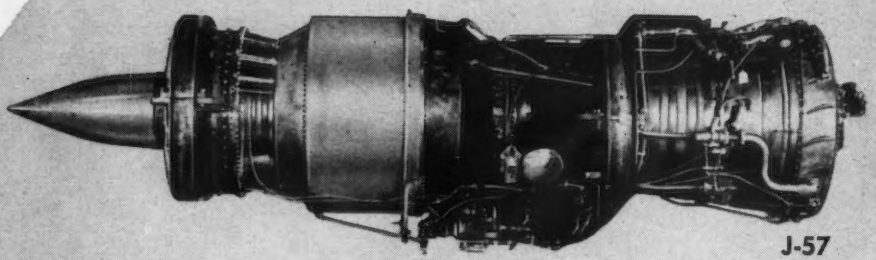

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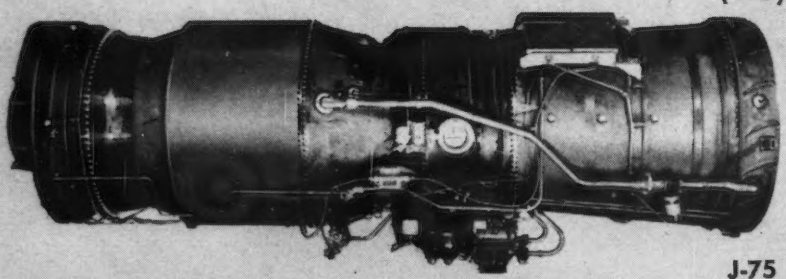

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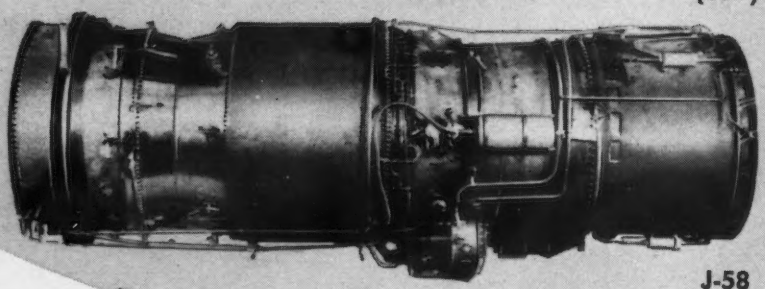

J-58

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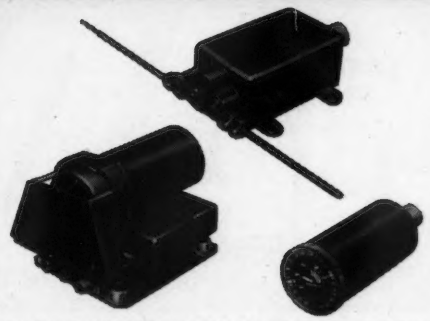

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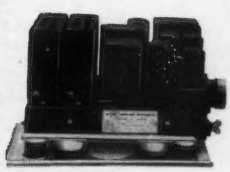

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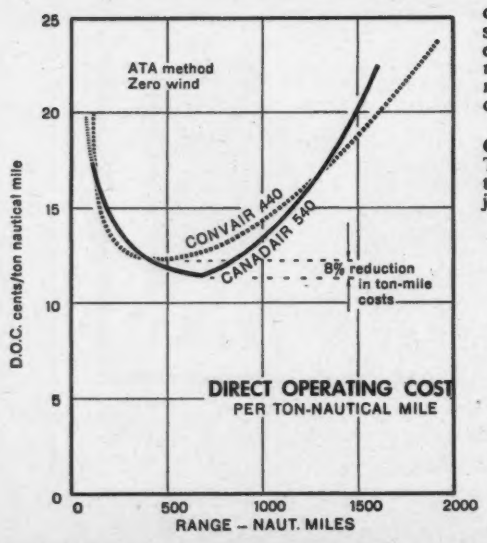
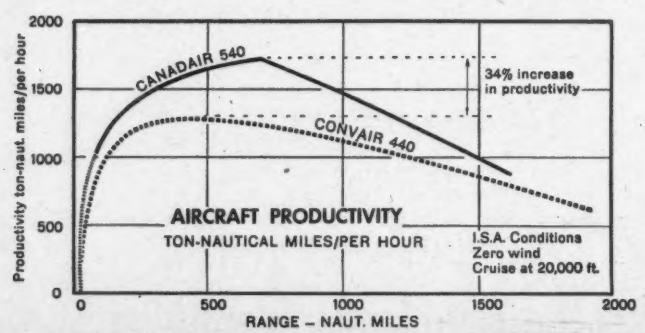


Graph at left, based on the ATA formula, shows that the direct operating costs of the "540" are as much as 8% lower than the "440". This applies particularly on stages over 400 miles; under 400 miles the graph indicates the two are approximately equal. Not reflected, however, are additional reductions in airframe and engine maintenance costs because of the more basic reliability of turbine engines and a minimum of vibration. This makes the "540" more economical than the "440" over any stage length.

Graph below shows the very definite superiority in aircraft productivity of the Canadair "540" over the "440", which is as much as 34% at their optimum ranges. This indicates that for equal annual utilization the "540" could produce 34% more ton miles; or equivalently, the Canadair "540" fleet size required to do the same job could be reduced by 34%, with a consequent saving in capital investment.



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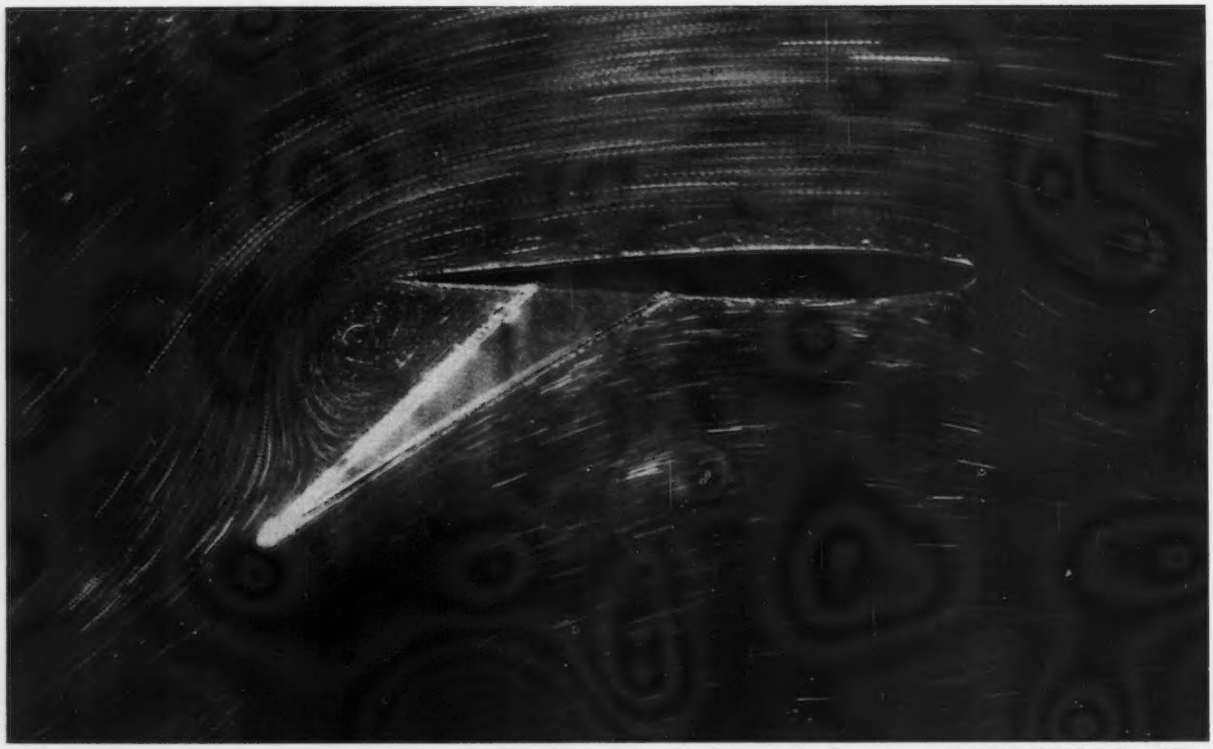
FLOW VISUALIZATION



National Research Council Photo

Aerofoil with Zap-type flap with suction applied at inner surface of flap during tests in a water tunnel. Aluminum particles added to water to obtain flow visualization **(See page 304).**

EDITORIAL

A CANADIAN REQUIREMENT FOR CANADIAN VTOL

At a meeting held recently in Ottawa to study the possibilities of VTOL equipment and its uses in the north country, several ways of designing such aircraft were explored.

However, no indication was given that any of the three Armed Services or the Federal or any Provincial Government has a definite requirement for such aircraft. In fact, the Air Force has found it possible to service the Mid-Canada Line and the DEW Line without VTOL, apart from the use of helicopters as auxiliaries, and the impression gained is that maybe there is no positive demand for a VTOL aircraft for such work.

However, my feeling is that there is big scope for such aircraft and that a demand should be formulated for a machine carrying 5 to 6 tons of payload over 200 to 300 miles. The point is, who will make the requirement? A requirement must include the ordering of prototypes of a short production run. It is useless making a requirement unless there is a serious intention to buy.

Whether or not people outside Canada lay down a requirement for a VTOL aircraft has nothing to do with the matter. The requirement under discussion is a Canadian one which should be defined in Canada and not elsewhere.

In the past, Canada has largely been content to make no requirement and buy off the shelf. I sense that this is in some respects still the attitude and it stems from the feeling that there are bigger and more experienced countries which can lead. I should like to point out that those days are gone forever and that there is nobody who can lead in this matter as well as Canada can.

It is also a waste of time to wonder whether this country can afford such development. Any country that can afford the St. Lawrence Seaway and the vast hydro-electric schemes now building can easily afford a big VTOL workhorse. The fact is that several very expensive (but potentially very profitable) projects are already being afforded and the tax burden on the average Canadian is still less than practically anywhere else in the world.

To sum up, technically this VTOL project can be done in Canada. Financially it is merely peanuts compared with the jobs now being undertaken. All that is needed is for some body or authority with the requisite dollars to frame a requirement, work it out with possible manufacturers, and place a development order. If it is not done, Canada will have to buy some rough approximation to what it wants from some foreign country, which is a pretty old-fashioned way of going about it.

B. S. Shenstone
Chief Engineer
British European Airways

FLOW VISUALIZATION

One of the ever present difficulties of low-speed wind tunnel testing is attendant upon the invisibility of the air! Time and time again it is necessary to obtain detailed information of the flow pattern of the air before certain test results are intelligible and, therefore, various means of airflow visualization are in constant use – wool tufts and liquid films on the model surfaces, smoke streams and dust particles injected into the airstream and so forth. There are occasions when it is desirable to be able to visualize the complete flow field of a model at a time when it is not possible or practicable to do so by means of the latter flow visualization techniques. In cases such as this, resort can be made to a specialized flow visualization tunnel, such as a smoke tunnel or a water tunnel.

In the National Research Council's Aerodynamics Laboratory, the water tunnel shown in Figure 1 is used for such detailed flow studies. The working section of this tunnel measures approximately 10 inches by 13 inches and has a maximum test velocity of 13 fps. A mercury lamp is suspended under the tunnel working section, as can be seen in Figure 1. This lamp produces a narrow light beam the length of the working section and projecting this through the glass bottom of the working section, planes of the flow field parallel to the flow velocity are illuminated; the flow in this plane is made visible if the water has had introduced into it particles such as aluminum powder, air bubbles, or coloured streams of water. To date aluminum powder has been used with the National Research Council water tunnel and a representative photograph showing the flow visualization obtained is given in Figure 2.

Figure 2 shows a two-dimensional aerofoil model with a large Zap-type flap in which some of the flow is sucked away at the inner surface of the flap; in effect the large wake that would exist ordinarily is sucked away, resulting in flow attachment to the flap with a consequent increase in flap effectiveness. The water tunnel is an ideal facility for investigating unorthodox aerodynamic devices such as this because not only can the whole flow field be observed in detail, but also the models are inexpensive and can easily be changed in order to explore the effect of a wide range of configuration variables. The flow pattern of an annular wing having a jet blowing from its trailing edge is shown in Figure 3.

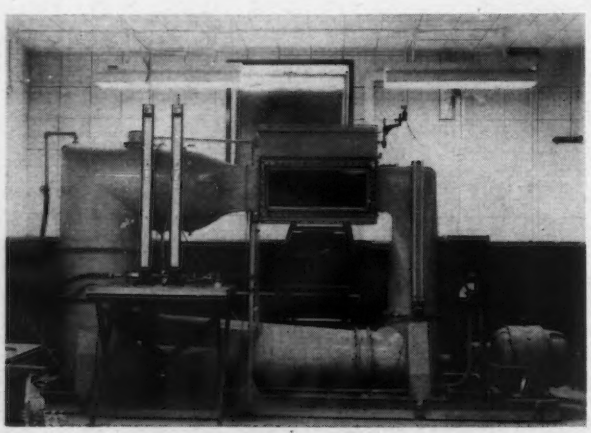


Figure 1
NRC water tunnel

Figure 2
Aerofoil with Zap flap

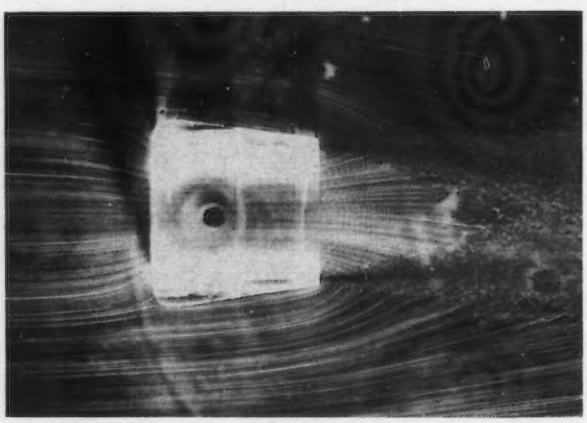


Figure 3
Annular wing with jet blowing out of trailing edge

The water tunnel has been used to obtain an understanding of many types of flow problems, for example, the flow in open bomb bays, flow over the bridges of ships, the flow at the leading edge of highly swept back wings.

P. J. Pocock
National Research Council

VTOL TRANSPORT CONFIGURATION STUDIES†

by F. C. Phillips* and K. Irbitis**

Canadair Limited

SUMMARY

A résumé is presented of a study done for the Defence Research Board, involving the preliminary design and analysis of VTOL aircraft configurations to satisfy an assumed military logistic supply requirement. The study assumed that the tremendous advantages of VTOL operations require little substantiation, and hence concentrated on the drawbacks and problems inherent in such aircraft. Five fixed-wing configurations were studied: Slipstream deflection; Tilting wing; Tilting ducted propellers; Jet lift turboprop; Turbojet propulsive wing.

On the basis of operational analysis based upon the design data evolved, it was concluded that the slipstream deflection and tilting wing types – especially the latter – offer real promise relative to the requirements of the assumed mission and corresponding civil applications.

Some suggestions are made as to specific research and development work needed to hasten the evolution of such aircraft.

INTRODUCTION

About two years ago, an extensive study of VTOL and STOL principles and possibilities was started at Canadair. Part of this study was presented as a technical paper at the Annual Meeting of the Canadian Aeronautical Institute in May 1956[1].

Shortly thereafter the Defence Research Board approached Canadair and expressed an interest in certain aspects of our work which resulted in a study contract in which five VTOL aircraft configurations were investigated.

This paper is a condensation of the above mentioned design study, made available by D.R.B.

REQUIREMENT

The Requirement stipulated an investigation and comparison of several VTOL aircraft configurations, employing different VTOL lift systems, and executing an assumed mission (Figure 1 – "split-level mission").

This mission was based on an assumed military logistic task, involving carrying an intermediate cargo load in a prescribed envelope, or an equivalent passenger load, over a prescribed short range, returning light without refueling.

The flight was to be performed at optimum altitude for 80% of the mission radius and at sea level for the remainder, this latter portion assumed to be in the neighbourhood of the target. Other mission profiles (e.g. the pseudo-civil "single-level" mission) could be investigated at the Contractor's discretion.

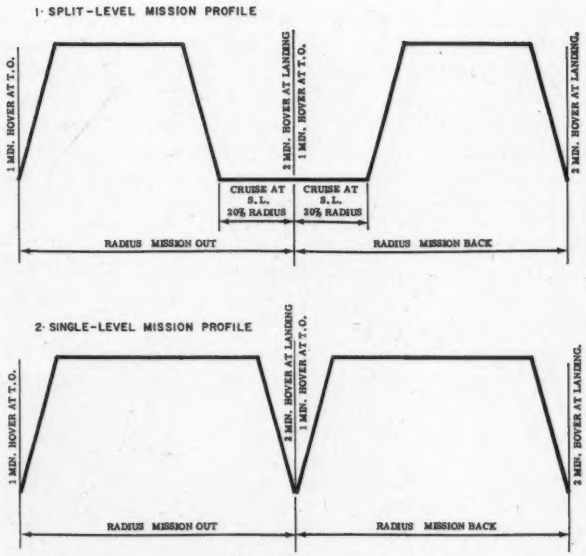

1- SPLIT-LEVEL MISSION PROFILE
1 MIN. HOVER AT T.O.
2 MIN. HOVER AT LANDING
1 MIN. HOVER AT T.O.
2 MIN. HOVER AT LANDING.
CRUISE AT S.L. 20% RADIUS
CRUISE AT S.L. 20% RADIUS
RADIUS MISSION OUT
RADIUS MISSION BACK
2- SINGLE-LEVEL MISSION PROFILE
1 MIN. HOVER AT T.O.
2 MIN. HOVER AT LANDING
1 MIN. HOVER AT T.O.
2 MIN. HOVER AT LANDING.
RADIUS MISSION OUT
RADIUS MISSION BACK

Figure 1
Mission profiles

Other notable elements of the Requirement were:

Fuel allowance for 6 minutes of hovering was to be made (1 minute for takeoff and 2 minutes for landing). Minimum reserves of 50% of hovering fuel and 10% of forward-flight fuel were to be carried. In addition, all brochure fuel consumption figures were to be increased arbitrarily by 5%.

Vertical takeoff, hovering and landing capability at full load with one engine inoperative were required under standard sea level conditions.

The capabilities of the designs under STOL conditions (500 ft distance to clear 50 ft on both takeoff and landing) were to be investigated.

DESIGN APPROACH

Five configurations attempting to satisfy the Requirement were investigated and are presented herein. The design approach has been one of eliminating lift and propulsion systems deemed incompatible with the Requirement, and of recognizing initially certain specified aircraft characteristics.

Lift and propulsion systems

The Requirement presumes STOL characteristics. STOL technique enables the allowable payload to be

---

†Paper read at the Annual General Meeting of the C.A.I. in Toronto on the 27th May, 1958.

*Project Engineer.

**Senior Engineer, Preliminary Design.

increased very substanitally, with attendant operating cost advantages. To achieve this goal and to cruise economically, one is forced to admit that all of these aircraft must have a wing with recognizable span.

For VTOL operation the wing alone is useless and direct lift means must be employed.

The helicopter rotor presents a very efficient VTOL lift system. It is however costly, complicated and airspeed limited. Therefore the approach taken was to discard the rotor as a direct lift means, for purposes of this study, and to seek substitutes.

The substitute lift and propulsion systems employed in the five investigated configurations were: propellers, ducted propellers and jet engines.

Bypass or ducted fan engines were not considered because no suitable engines were available or planned for availability in the near future. Afterburning turbojets were found to require excessive fuel loads to cope with the prescribed hovering time. Other powerplants – nuclear, rocket, piston etc. – were eliminated as not suitable for the design mission.

Selected configurations

The following five configurations were selected for investigation. They were identified with a type number CL 62 and dash numbers 1 to 5.

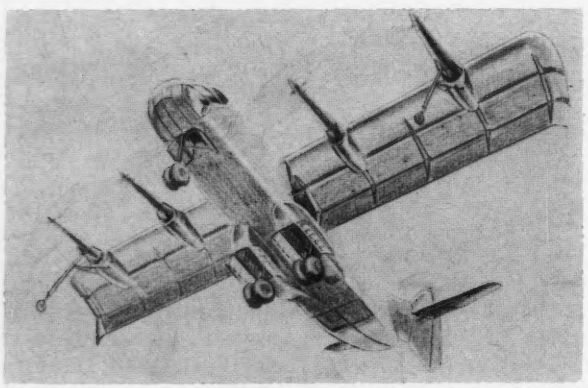


Figure 2
CL 62-1 in hovering

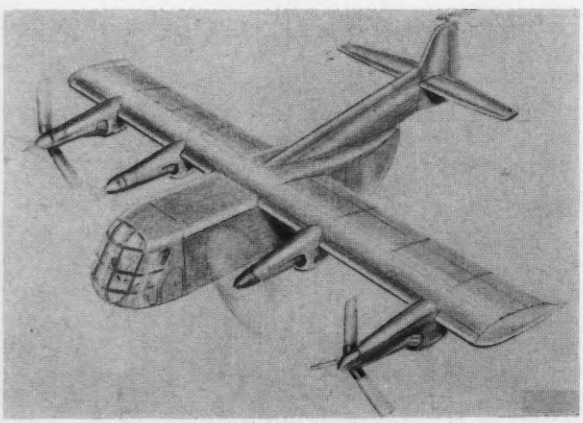


Figure 3
CL 62-1 in flight

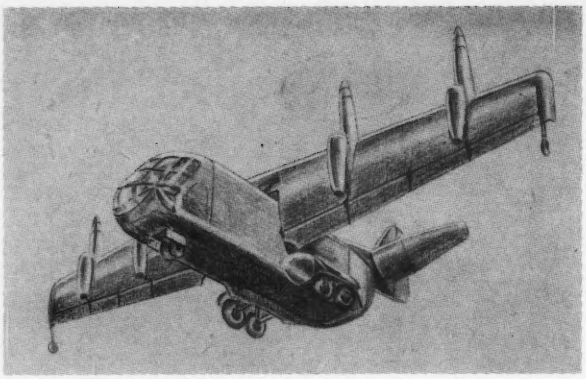


Figure 4
CL 62-2 in hovering

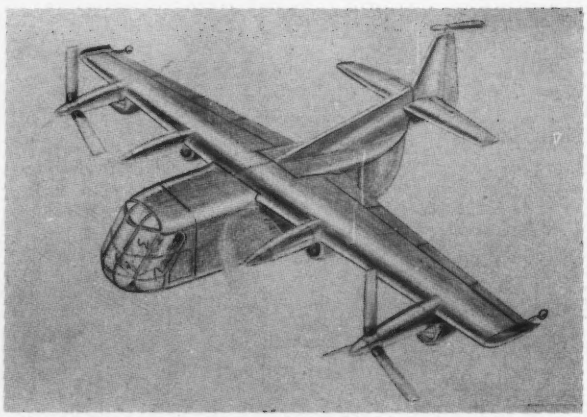


Figure 5
CL 62-2 in flight

CL 62-1 Slipstream deflection (*Figures 2 and 3*)

Four shaft turbine driven propellers, used for normal propulsion, would also be used in hovering. The slipstream would be deflected vertically by a very powerful flap system and the resulting reaction would provide lift. A hovering attitude of about 20° was considered highly desirable to maximize the lift for a given power input.

CL 62-2 Tilting Wing (*Figures 4 and 5*)

Four shaft turbine driven propellers would supply a thrust for propulsion as in the conventional airplane but would also supply lift in VTOL operation, for which the wing and nacelles would be rotated into a vertical position.

CL 62-3 Tilting ducted propeller (*Figures 6 and 7*)

Shaft turbines would drive ducted propellers mounted on the wing tips. In normal flight this system would supply thrust for propulsion; in VTOL operation the ducted propellers would rotate 90° to supply lift.

CL 62-4 Jet lift turboprop (*Figures 8 and 9*)

Turboprop forward propulsion would be used, but for VTOL operation a series of small lightweight turbojets, mounted vertically along the fuselage sides, would furnish lift.

CL 62-5 Turbojet propulsive wing (*Figures 10 and 11*)

VTOL lift would be provided by a series of turbojets contained in the wing aft portion, which would be

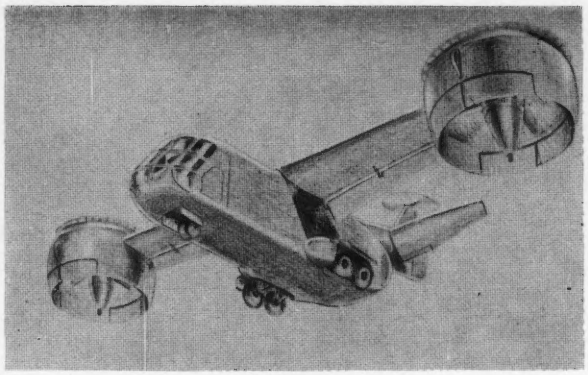


Figure 6
CL 62-3 in hovering

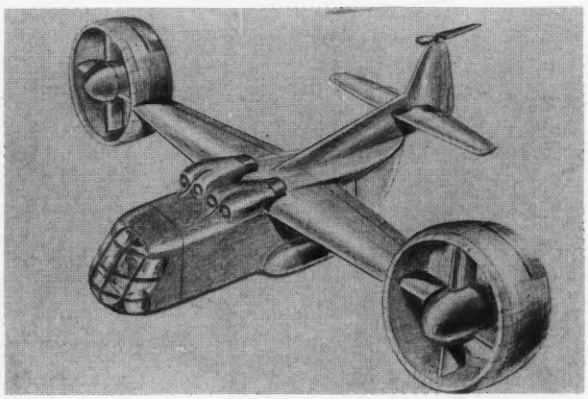


Figure 7
CL 62-3 in flight

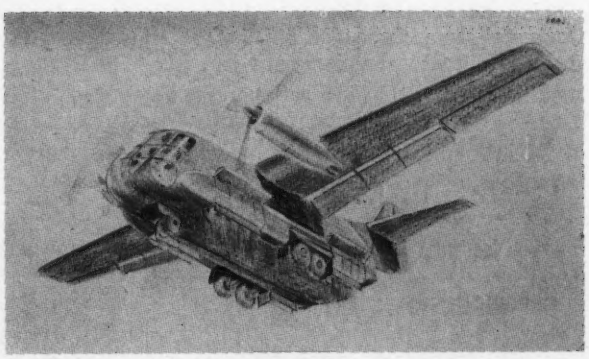


Figure 8
CL 62-4 in hovering

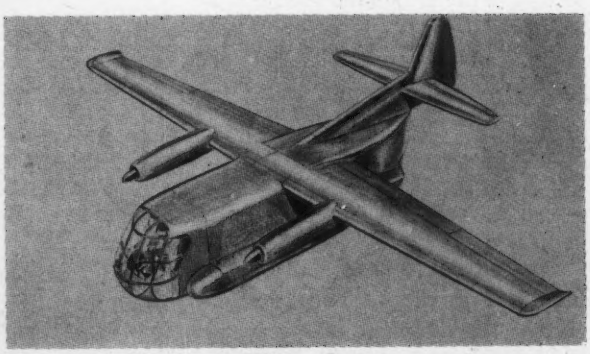


Figure 9
CL 62-4 in flight

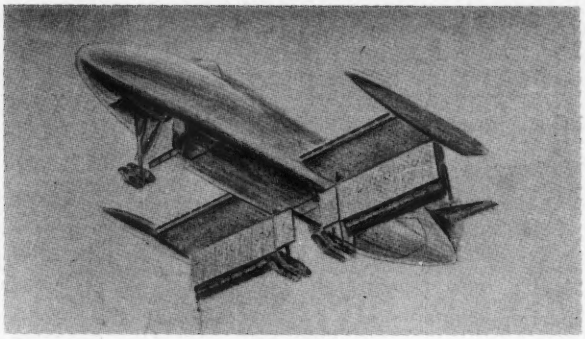


Figure 10
CL 62-5 in hovering

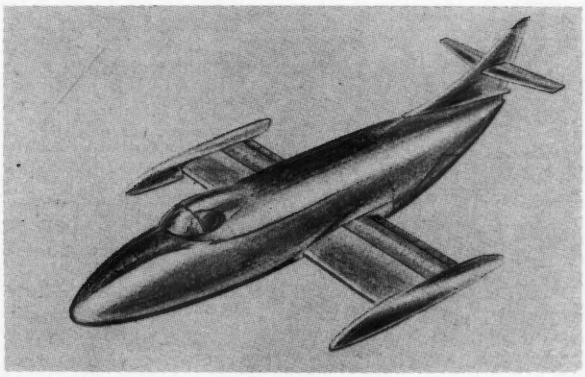


Figure 11
CL 62-5 in flight

deflected vertically, and by several jet engines in the forward fuselage. Some of the wing-mounted engines would be used for propulsion.

Main components

General

The high-wing arrangement of the first four configurations was used to obtain propeller ground clearance with convenient cargo floor height. In the fifth – the pure jet aircraft – a low wing was chosen to avoid jet blast on the fuselage and to facilitate landing gear design.

The main determining factor for the first two aircraft was the propeller diameter. It was set so as to obtain sufficiently low disc loading for good hovering efficiency with single-rotation propellers, while providing a propeller clearance compatible with convenient cargo floor height and a reasonable landing gear length.

Wing

The span of the slipstream-deflection (-1) and tilt-wing (-2) aircraft was determined by the selected propeller diameter, by a decision that the entire span should be affected by slipstream to optimize VTOL and STOL efficiency, and by a decision that four propellers would be used to give a reasonable order of magnitude of wing span. The same span was used for the tilting ducted propeller (-3) and jet lift turboprop (-4) configurations. The chord for second, third and fourth configurations was set arbitrarily to obtain the wing loading of approximately 40 lb/sq ft. A longer chord was chosen for the first configuration in order to obtain a wing-flap

combination powerful enough to provide the slipstream deflection required in VTOL operation.

The size of the wing for the fifth configuration was set by the size of the small turbojets installed in the aft wing portion.

Empennage

The horizontal stabilizer of the first three aircraft was of the free floating type, servo tab operated; the fourth configuration would have a conventional horizontal tail.

The horizontal and vertical stabilizers for these four aircraft would be attached to a large structural dorsal fin which would be integral with the fuselage top structure. On the first, second and third aircraft a tail propeller, for longitudinal control in VTOL hovering, was mounted at the top of the vertical tail. The -5 empennage was conceived as conventional except for a power-boosted interrelated movement of stabilizer and elevator.

Fuselage

A squarish fuselage, utilizing sandwich panels extensively and having a clamshell type of rear door, was chosen for the first four configurations; see Figure 12. An alternative fuselage aft end arrangement employing a ramp door and ducted tail propeller was considered also.

Turbojet propulsion in the fifth configuration required high altitudes for efficiency. Since pressurization was mandatory, the squarish fuselage shape of the other aircraft was not structurally feasible here.

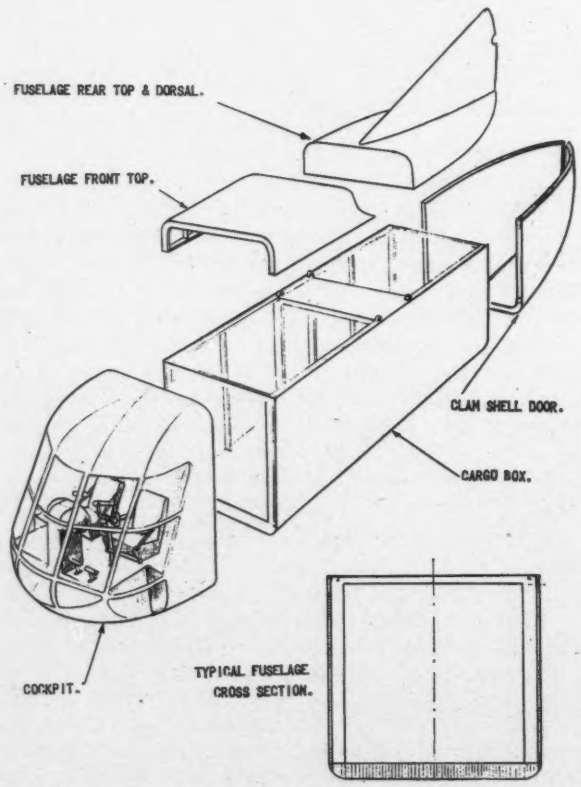


Figure 12
CL 62-1 to -4 fuselage

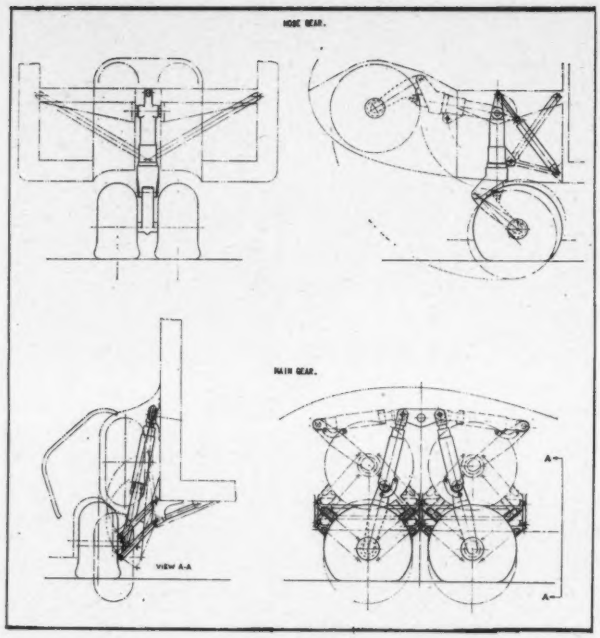


Figure 13
CL 62-2 landing gear

Landing gear

Landing gear design presented problems due to the large wheel sizes required for obtaining low footprint pressures. Retraction of a typical main gear into the blister fairing is shown in Figure 13. Development work, on tires inflatable in flight for example, could reduce the drag penalty appreciably, but it was considered premature to depart from conventional practice here.

For the fifth, the pure jet configuration, a track type landing gear was felt to be required and was investigated in some detail.

Main systems

Power systems

For configurations -1 to -3 the power system consisted of thrust producers in the form of propellers or ducted propellers, driven by a number of powerplants. For -4 the system was made up of turbojets for VTOL lift, and two turbine engine-propeller combinations for propulsion. In the -5 turbojets were used for VTOL lift as well as for propulsion.

Limited lifting efficiencies (in comparison with helicopters) of the thrust producers for VTOL aircraft require better specific powerplant weights than for normal aircraft if a reasonable operational economy is to be achieved. In order to obtain an acceptable cruise efficiency with high-lift, wide-blade propellers, designed primarily for hovering, an engine capable of working economically below its optimum rotational speed is needed.

The above requirements can only be met by an advanced powerplant of the free turbine type.

The characteristics of the engines were based on a conservative extrapolation of specific current free turbine engine developments. Similarly, specific engine char-

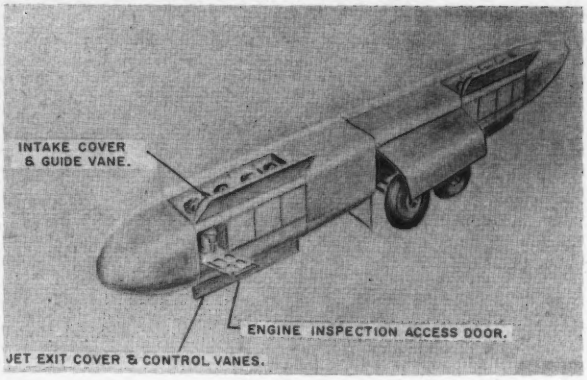


Figure 14
CL 62-4 lift engine installation

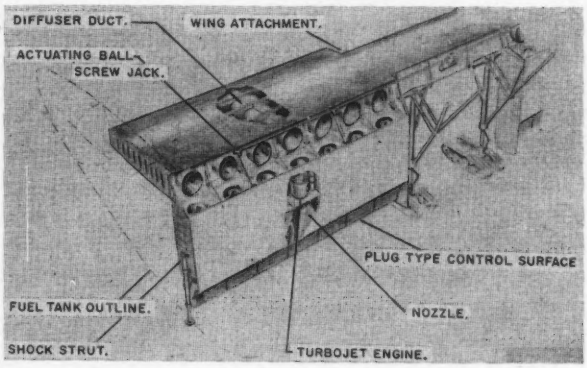


Figure 15
CL 62-5 propulsive wing

acteristics were used in the case of the turbojet powerplants for –4 and –5 configurations.

A first approximation to the installed horsepower required in an aircraft of a given weight can be obtained by dividing the weight by the static thrust per horsepower developed by the propeller. Suitably designed propellers can give 4 to 5 lb of static thrust per horsepower. On account of the engine failure case, the total horsepower thus arrived at must be provided by 3 of the 4 engines, so that the installed horsepower is 4/3 of this amount. In the case of the jet-lift types, the installed thrust of the total number of engines less 1 (or 2, where failure of 1 engine requires cutting another to maintain balance) must equal the weight.

An 8 engine installation was considered as an alternative for the –2 aircraft. This version, designated –2a, was carried through several phases of the investigation, as explained below.

Installation of the 16 VTOL turbojets in the fairings at the fuselage sides of the –4 configuration is shown in Figure 14. Figure 15 shows the wing of the –5 with 14 turbojets installed side by side in the aft portion, deflected as for VTOL flight.

Thrust systems

For –1 and –2 the largest possible propeller diameters were needed for hovering efficiency with single rotation. The diameter actually used was the largest allowable, considering ground clearance of the propeller.

A takeoff tip speed of 850 ft/sec was selected to give low noise level and low compressibility losses. Hovering performance calculations showed that three-bladed propellers – with consequent weight savings – could be used if sufficiently high blade camber and activity factor choices were made. An activity factor of 170 was selected for both –1 and –2 configurations. The –4 propellers were chosen for good cruising efficiency, there being no hovering design condition.

The –3 propeller and shroud geometries were assumed to be geometrically similar to the best wind tunnel test configuration of Reference 2. This was the only source of comprehensive data available at the time, and was used throughout. Aircraft ground clearance limited the diameter; the limiting value was used to favour the critical hovering efficiency. Use of the hovering blade angle corresponding to peak static thrust efficiency fixed the takeoff tip speed at 700 ft/sec, which in turn set the engine-propeller gear ratio. Figure 16 shows the general arrangement of the ducted propeller.

The Requirement stipulated that these aircraft must be capable of hovering with one engine inoperative. It was assumed at the outset that there must be at least four lift engines to satisfy this condition without excessive installed powerplant weight. Obviously it must be assured that engine failure would not cause a critical aircraft control problem, even in the event of engine failure during hovering; provisions to avoid such loss of control would vary with the aircraft configuration. In the –1 and –2, symmetry of propeller thrust following engine failure was provided by gearing, shafting and clutches interconnecting the four engine-propeller units; by this means a failed engine would automatically disengage and the output of the remaining three engines could still be divided equally among the four propellers.

An alternative to mechanical propeller interconnection in –1 and –2 would be the use of eight rather than four engines. Here the interconnection would be via engine controls such that failure of one engine would automatically deactivate the symmetrically-opposite engine; the installed power would be almost the same as for the basic aircraft, but the weight and complication in the mechanical interconnection system could possibly be reduced appreciably.

In the –3, the long shaft driving the ducted propellers from the fuselage-mounted engines provided intercon-

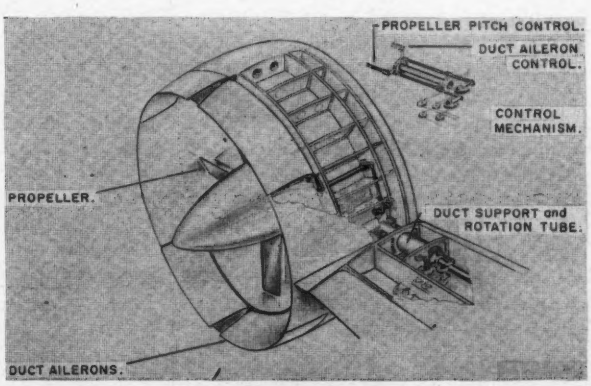


Figure 16
CL 62-3 ducted propeller

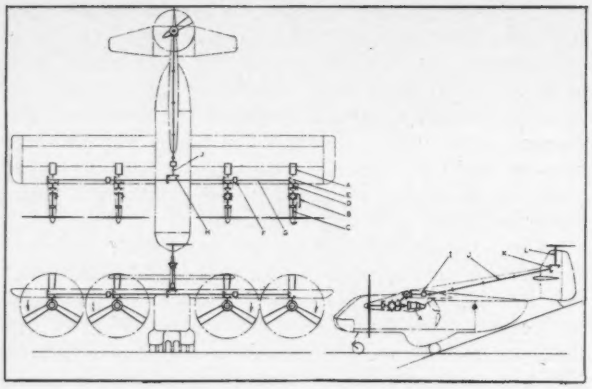


Figure 17
CL 62-1 power transmission system

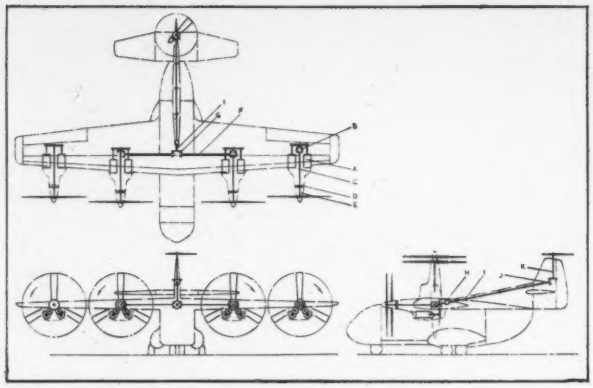


Figure 18
CL 62-2a power transmission system

nection and hence thrust symmetry following engine failure.

Mechanical interconnection of the turbojets of –4 and –5 would be meaningless, hence coupling of engine controls was assumed for both aircraft. For –4 anti-symmetric coupling of controls would be required to preserve longitudinal and lateral trim upon loss of an engine.

The number and ratings of the engines used in each design are consistent with the requirement to hover with one engine inoperative, assuming the above power interconnection schemes.

Power transmission systems

In the –1, –2 and –3 aircraft the engine power would be transmitted by a system which would provide (Figure 17):

(a) power transmission from engines to main propellers
(b) interconnection between the individual transmissions
(c) power transmission to the tail control propeller

This system, for example in –1, would entail an over-running clutch and planetary gear box between individual engine and propeller, interconnecting gearing and shafting between engines tieing into the system between engine clutch and gear box, plus a gearbox and shafting to the tail propeller driven off the interconnecting shafting. Further idler gears would be required in two engine gearboxes to provide a symmetrical propeller rotation pattern; special clutches in the outer interconnecting shafts would be needed to permit cruising operation with two engines shut down; a clutch in the tail propeller drive would allow disconnecting this propeller in forward flight.

Transmission systems similar to the above were investigated for –2 and –3. The –2a variant (Figure 18) was studied solely to determine if the –2 could be improved in the overall sense using coupling of engine controls to permit reduction of the transmission system to the minimum. Two engines in each nacelle would be connected to a single propeller by overrunning clutches and gearbox; no extra-nacelle shafting was used except for the tail propeller, which was kept as in –2 arbitrarily for purposes of comparison.

Control systems

No quantitative control analyses were made during

FLIGHT CONDITIONS	Control Functions	CL-62-1	CL-62-2	CL-62-3	CL-62-4	CL-62-5
VTOL and HOVERING	Pitch	Tail Propeller	Tail Propeller	Tail Propeller	Differential Jet Thrust	Control Engine Thrust
	Roll	Differential Propeller Pitch Control	Differential Propeller Pitch Control	Differential Propeller Pitch Control	Differential Jet Thrust	Differential Jet Thrust (lift engines)
	Yaw	Ailerons	Ailerons	Duct Ailerons	Jet Exit Control Vanes	Jet Exhaust Plug Ailerons
TRANSITION	Pitch	Tail Propeller ↓ All Movable Hor. Tail	Tail Propeller ↓ All Movable Hor. Tail	Tail Propeller ↓ All Movable Hor. Tail	Diff. Jet Thrust ↓ Elevator	Diff. Jet Thrust ↓ All Movable Hor. Tail
	Roll	Diff. Prop Pitch Control ↓ Ailerons	Diff. Prop Pitch Control ↓ Ailerons	Diff. Prop Pitch Control ↓ Duct Ailerons	Diff. Jet Thrust ↓ Ailerons	Diff. Jet Thrust ↓ Plug Ailerons
	Yaw	Ailerons ↓ Rudder	Ailerons ↓ Rudder	Duct Ailerons ↓ Rudder	Jet Exit Control Vanes ↓ Rudder	Plug Ailerons ↓ Rudder
CRUISE	Pitch	All Movable Hor. Tail	All Movable Hor. Tail	All Movable Hor. Tail	Elevator	All Movable Hor. Tail
	Roll	Ailerons	Ailerons	Duct Ailerons	Ailerons	Exhaust Plug Ailerons
	Yaw	Rudder	Rudder	Rudder	Rudder	Rudder

Figure 19
CL 62 control systems

this study, by previous agreement. However, for design purposes control means were studied briefly for each configuration and flight regime – VTOL, transition and normal flight. Figure 19 represents the control schemes assumed. In many cases the control means should be potentially adequate, if intuitive reasoning and existing literature can be relied upon. In other cases – for example, VTOL roll control on –4 – the scheme envisaged may prove impracticable. Assuming that control means were at hand for steady-state flight regimes, there would remain substantial problems in providing adequate control during transient conditions, when aircraft flying qualities and control means would be changing simultaneously. Involved dynamic analysis plus free-flight model and/or aircraft flight data would be required to evolve satisfactory controls for any of the five aircraft.

Aside from the control systems of Figure 19, there would be other systems bearing directly upon control and trimming of the aircraft. Powerplant controls, operation of the –1 flap, tilting of the –2 wing, tilting of the –3 shrouded propellers – each of these items would have to be properly designed mechanically and operated with correct phasing during transition. Figure 20 illustrates the nature of the –2 wing tilting mechanisms, together with control runs, which must pass into the wing through the wing pivoting axis; drawings such as this were prepared to aid in making feasibility studies of the more difficult mechanical features.

Other systems

Specific investigations of other systems, such as instrumentation, hydraulic, electrical, heating and ventilating, were not made because there appeared little doubt as to feasibility. Statistical weight and balance estimates for these items were made, considering the functioning of the individual system in the aircraft role.

STRUCTURES AND WEIGHTS

The primary purpose of the structural analysis was considered to be confirmation of statistical component weight estimates. First-approximation *V-n* diagrams were drawn up for the various aircraft. Where weight estimation using empirical data was apt to be inaccurate, structural layouts and analyses were made. Wings, landing gears and power transmission systems required such structural attention; some work was also required for

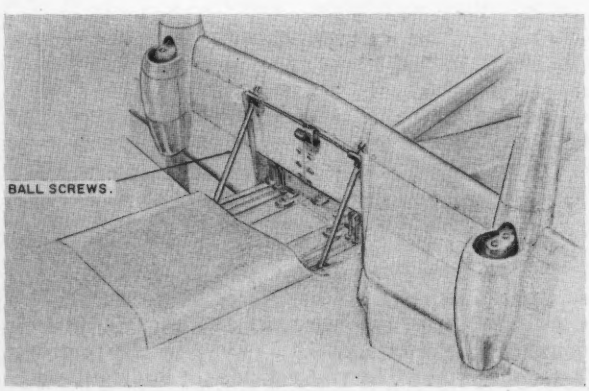


Figure 20
CL 62-2 wing tilt mechanism

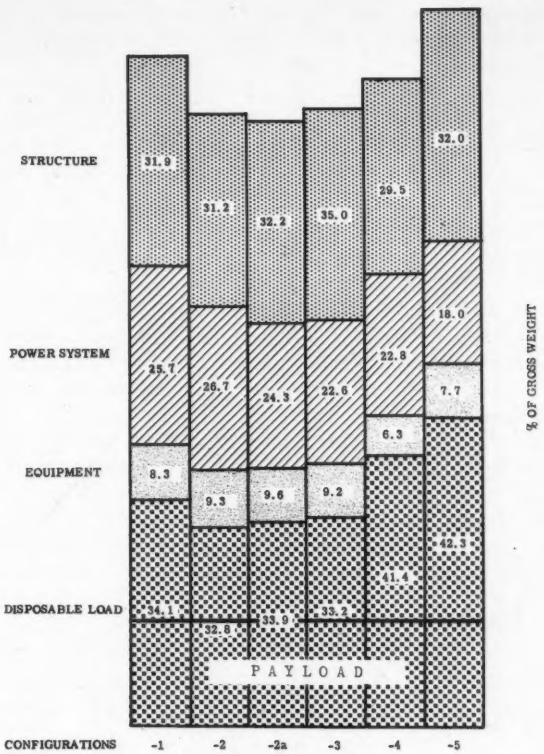


Figure 21
CL 62 weight comparison

the –5 fuselage, which differed appreciably from the others in regard to shape and pressurization.

Methods used for the weight analysis were directed towards obtaining accurate quantitative indication of empty and gross weight. Data relating to certain features in the various configurations were non-existent. It was necessary to combine empirical estimates based on current trends with:

(1) preliminary stress analysis of primary structures, or
(2) estimates from design layouts (notably the power transmission systems), or
(3) provisional allowances for special installations.

Evaluation of gross weight was made more difficult than usual in that not only was the fuel load required to be compatible with the mission profile, but in addition the installed power had to be adequate for hovering. By trial and error the various compatibilities were achieved.

Figure 21 shows a dimensionless weight comparison of the investigated configurations.

The –2 aircraft presented special balance problems because of the wing tilt feature. The design had to be arranged in such a way that in normal flight the aircraft center of gravity would be near the quarter-chord, while permitting it to be near the thrust axis in VTOL flight. This was achieved by proper location of wing tilt axis and location of powerplant items relative to the wing.

AERODYNAMICS

Aerodynamic investigations were confined to (a) performance estimates, in particular block speed and the associated required fuel loads for the missions, and (b)

determination of hovering power required, together with a check of hovering thrust reserve with one engine inoperative.

Normal-flight performance estimates were made using conventional methods. Adequate allowances were made for slipstream drag and the unrefined aerodynamic shapes of the first four configurations. Propeller efficiencies were calculated using Reference 3; shrouded propeller efficiency data were taken from Reference 2. As required, all engine manufacturer's fuelflow data used were arbitrarily increased by 5%.

It was expected that, with so much installed thrust, economical cruising would be done with some powerplants shut down. Analysis showed that for −1, −2 and −3 use of half of the engines corresponded closely to the optimum, hence this basis was adopted; provision was made for intake shutters in the engine nacelles, and feathered propeller drag was accounted for in −1 and −2 drags. Since the −4 would have forward propulsion intended only for cruising, there was no engine shutdown case to consider. In the −5, analysis indicated that eight of the fourteen propulsive engines should be utilized.

For the first four aircraft it was found inadvisable to pressurize the fuselage in order to gain the relatively small increases in economy corresponding to high altitude cruising. Accordingly, 10,000 ft was taken as cruise altitude. In the case of −5, turbojet propulsion required high altitudes; 45,000 ft was selected for cruising since higher altitudes offered little additional economy for short ranges.

Hovering thrust reserve was estimated for all aircraft at sea level with one engine inoperative. Free still air was assumed, since little or no data on ground effect for use in VTOL work are available. Power allowances were made for losses in gearing and shafting, where applicable, and for driving accessories. Likewise, slipstream drag and deflection losses were taken into account where appropriate. A small reserve thrust was provided for, to permit trim in hovering and acceleration into forward flight.

OPERATIONAL CONSIDERATIONS

Introduction

As outlined, preliminary work was done on five configurations designed to satisfy the Requirement. The best configuration would be determined ideally by a detailed comparative operational analysis, each aircraft being presumed to be an optimum design of its type. Since the present five configurations were not optimized, an involved operational analysis could not be justified. However, even a qualitative analysis can point up important pros and cons, and it was with this idea in mind that an operational analysis was attempted. The more important operational *problems* are mentioned below.

VTOL flight operations

Operation on or near the ground at high engine output would create strong air movements near the aircraft. The strength of these artificial winds would be proportional to the lift disc loading, i.e. the order of increasing wing velocity would be −2, −1, −3, −4 and −5. In the latter two (jet-lift) configurations, there would also be a serious exhaust temperature problem for the ground surface, landing gear and airframe. The slipstream velocities for −2 would correspond approximately to those of a Dakota aircraft at high power. Obviously these air velocities would have important effects on operation of all aircraft, and the exhaust temperatures would impose serious limitations upon utilization of −4 and −5 from unprepared sites.

Flight near the ground in the −1 would probably be more difficult than in the others because (a) of the need to assume a tail-down attitude to obtain maximum slipstream deflection, (b) of the relatively large longitudinal trim requirement, and also (c) of greater sensitivity to gusts in respect to power required for flight. In the −4 auxiliary jets using engine bleed air would perhaps be necessary for adequate roll and yaw control near the ground.

The technique for converting from VTOL to forward flight and vice versa would differ for each configuration, but in each case would be the result of experimentation with models and prototype aircraft. The conversion would appear to be more difficult in the tilt-wing −2 inasmuch as the 90° wing incidence change would involve passing through a regime of separated flow over the wing. This regime is not the normal wing stall because of the energizing and straightening effect of the slipstream on the wing flow; it is known that a series of free flight model tests of the Hiller X-18 tilt-wing aircraft has been concluded successfully. By contrast the conversion of the −4 should be straightforward, and that of the −1 should be comparable to a highly-flapped, overpowered airplane.

STOL flight operations

It is our feeling that any successful VTOL transport will be able to utilize runways where available in order to increase payload. All five aircraft studied were intended to have STOL capability, but it was clear that there would be a variation in degree. In a supply role requiring VTOL operation at an unprepared unloading point, the overload would probably be limited for all aircraft by ability to land vertically at this point, rather than by takeoff runway length at the base of supplies, (i.e. STOVL operation); under these conditions the allowable cargo overload would be the fuel burned en route to the unloading site.

Operation over rough ground would be more difficult in the −1 because of the more critical propeller clearance; compare Figures 2 and 4.

Crosswind landing gears would be very desirable for all aircraft, in that where the runway available is very short, it is apt to be the sole runway. Thus the crosswind angular component at times would be large, especially since the operating speeds would be relatively low.

The STOL payload from a given short runway would probably be highest for −1 or −2; the poorest performance would probably correspond to −3.

Loading and unloading

Cargo handling at an unprepared site is benefited by a low cargo floor, although truck-bed height is of questionable value. However, it is clear that the relatively high floor of the −5, and the difficulty of loading through a pressure bulkhead, would compromise its utility. This would loom large in an economic analysis, since time on

the ground penalizes more severely the faster aircraft. Further, air dropping of cargo would be more involved because of the additional obstacle of the pressure bulkhead.

Serviceability and maintainability

Aircraft maintenance would tend to be increased by operation from unprepared sites in combination with the high induced velocities of propellers or jet lift engines.

Powerplant maintenance procedures would be required to recognize that engines would operate various amounts per flight hour. Design would have to permit quick exchanges in the field so that powerplant wear could be equalized.

The power systems of all five aircraft would involve an appreciable number of units. If one enumerates engines, gearboxes and propellers, the various aircraft (including the eight-engine -2a) have roughly the same *number* of power system units, but the jet lift -4 and -5 have far less *kinds* of units. While it cannot be said from this that -4 and -5 are obviously superior in maintainability, since the addition *kinds* of units in -1, -2 and -3 involve items probably requiring infrequent maintenance, nevertheless there is a potential disadvantage here for the propellered aircraft that warrants intensive operational analysis.

Operational safety

Beyond safety aspects already apparent by consideration of one-engine-inoperative performance, propeller clearance, stability and control etc, there are various other factors worth noting. Several of these factors were studied in detail.

Propeller failure in forward flight would create for -1 and -2 an emergency comparable to that in a four-engine airplane. Failure of the -3 shrouded propeller would be more serious than in a two-engine airplane because of the large moment unbalances created and the implications of damage to the shroud. Propeller failure in VTOL flight close to the ground would compare with helicopter rotor failure, i.e. would cause a heavy landing or crash. Tail propeller failure in -1 under VTOL conditions would be more serious than in -2 or -3 because of the degree of dependence upon it to provide trim. Propeller failure is remote statistically but the design must be such that the probability is made extremely low; this should be easier to achieve than in helicopter rotors.

Interconnecting shaft or gearbox failures in -1 and -2 would be similar to engine or propeller failure, depending on location in the system of the failed item. However, failure in -3 of interconnecting shaft or fan drive gearbox would approximate fan failure; these items are under substantial load in normal flight, whereas the corresponding items in -1 and -2 have a low load except after engine failure.

Failure of various actuating systems would create emergencies, particularly during transition or VTOL flight. Note that STOL capability would reduce vulnerability to failures of various sorts.

Crash safety should receive major design attention. The high wing disposition for all except -5 would warrant incorporation of such features as longitudinal crash beams beneath the cockpit and cargo floor, and energy-absorbing structure beneath floor and in fuselage walls beneath and ahead of the wing.

Relative to the -1 and -2 as a base, there would be additional crash and fire hazard for personnel in -3 since the engines are mounted above the fuselage. Excess fuel during starting of the -4 lift engines would drain onto the ground to create a danger of fire; in -5 there would not be the same problem if the engines were started in the horizontal attitude. However, even if excess starting fuel were eliminated as a hazard, the turbojet lift engines of both -4 and -5 would pose real fire hazards to any unprepared sites having combustible surface materials. Here is a very serious limitation on the use of these two aircraft.

Visibility from VTOL aircraft cockpits must be excellent. The -5 would be handicapped in this respect by the need to minimize transparent areas in a pressurized fuselage. Visibility in the -1 would be reduced to the extent that a nose-high attitude would be needed for maximizing slipstream deflection in hovering.

Since this class of aircraft could not hope to operate near or within enemy territory at altitude without danger of detection and interception, the Requirement specified a portion of the mission near the unloading site to be flown at sea level, in order to increase mission secrecy. Since the effect of increased airspeed at terrain altitude reduces the chances of detection, at least up to, say, 300 kts speed, the work included a study of this and the effect on payload. All aircraft except -4 could attain in emergency an airspeed of 300 kts.

If the sea level operation were performed at such a speed, the VTOL cargo allowable within the engine-inoperative terms of the Requirement would be greatly reduced. The -5 would have an advantage here, since the operating speed could be increased to 300 kts at very little increase in fuel required.

Vulnerability to ground fire was examined. Over the unloading site, transition to VTOL flight would be a vulnerable short period, particularly if the nature of the flight characteristics during transition were to prescribe considerable altitude above the surrounding area. In this respect the -1 and -4 configurations might have substantial advantages in that the transitions should be more straightforward, whereas the separated flow regimes involved in -2 and -3 transition flight should require more terrain clearance.

Potential danger to the aircraft from ground fire strikes would perhaps be more critical in -3, where the implications of damage to propeller, shroud, gearbox and shafting damage could be serious. The -5 should prove to be least susceptible on this point.

Cost analysis

Production aircraft first cost predictions were made by summation of individual, careful analyses of airframe and equipment. It appeared that the -2 would be the least expensive, with the -5 at the opposite end of the scale due to the relative complexity and refinement of design.

An operating cost analysis using civil airline procedures was undertaken with the purpose of indicating only if any of the aircraft were especially uneconomic

on a relative basis. It was realized that accurate cost forecasting would be impossible because of the unorthodox nature of the mission and aircraft, and the associated unknowns – maintenance and overhaul times etc.

The analysis showed the following cost trends:
(a) The –1 and –4 would be relatively more costly (direct cost per ton-mile) for both missions and various utilizations (flight hours per year). These aircraft would also be more expensive in terms of dollar investment in fleet per unit of transportation (ton-miles per unit time).
(b) The –5 would be the least expensive to operate for either mission and would represent the lowest fleet investment per unit of transportation for the single-level mission, if a utilization equal to or only slightly below that for the other aircraft could be attained.

Except for the operating costs of the –5 single-level mission, the differences between the extremes of the significant cost data were 15% or less. Thus firm conclusions cannot be drawn when the inherent possible errors are recognized.

Operational flexibility

However good an aircraft may be for the design mission, it is not a good choice unless it has good operational qualities for off-design conditions. Obviously the operational flexibility of the five configurations should be compared. A short study was made along these lines, assuming the design (split-level) mission as a base.

The jet propelled –5 aircraft, as expected, proved be the most sensitive to changes in operating conditions, as indicated by payload allowable under the altered circumstances. Thus the –5 payload would vary most with changes in hovering time required, and with requirements to loiter or divert to an alternative destination, especially at low altitude. Likewise an imposed reduction of operating altitude would be most harmful to –5 payload; this means also that reduction of the sea level cruise portion of the mission would be very helpful and extension of the altitude cruise portion least harmful to payload. The –5 operating costs would be most sensitive to time spent on the ground between missions.

The jet-lift –4 would be keenly affected by changes in hovering time, and the –3 payload should benefit least from an opportunity for STOL operation. Otherwise all aircraft aside from –5 should be fairly flexible operationally, as compared with turboprop airplanes.

DISCUSSION AND CONCLUSIONS

The work outlined above did not constitute an exhaustive analysis but it was possible nevertheless to draw a number of conclusions with little fear of serious error. In particular, an examination of the disadvantages of each configuration is helpful:

–5 (Turbojet propulsive wing)

(a) highest aircraft cost in production

(b) greatest amount of research and development work required – aerodynamic, structural, landing gear, powerplant installation

(c) tends to have low operating costs, but for split-level mission of Requirement has the highest fleet investment per unit of transportation

(d) tends to have the operational inflexibility of other jet aircraft – very economic on longer range, high altitude missions, but less applicable to missions involving holding, as in the Requirement

(e) difficult to load and unload, which could reflect seriously on aircraft utilization in operations involving unprepared sites

(f) engine exhaust of high velocity and temperature would create serious fire and other hazards in VTOL operations from combustible surfaces

(g) more recent knowledge of substantial engine overweight would worsen appreciably the economics presented here

–4 (Jet lift turboprop)

(a) operating costs relatively high

(b) engine exhaust hazards apply to surrounding surface area and to landing gear

(c) low maximum speed limits possibility of sea level cruising at high speed to escape enemy detection and interception

(d) actual lift engine overweight would worsen appreciably the economics presented here

–3 (Tilting ducted propeller)

(a) much research and development work required on structural aspects of combined wing and shrouded propeller, also on aerodynamics of shrouded propeller to achieve in practice the assumed propulsive efficiencies

(b) difficulty of design and critical dependence on integrity of shroud, propeller and shafting; vulnerability to ground fire because of this

(c) crash safety probably poorest, considering engine placement

(d) most serious air blast problems of all propellered configurations during VTOL operations

(e) probably poorest STOL performance

–2 (Tilting wing)

(a) transition flying qualities problems will require much research and development work; transition technique may require sufficient altitude to raise questions of vulnerability to enemy fire

(b) interconnection of engines and propellers will pose difficult design problems

–1 (Slipstream deflection)

(a) high production aircraft cost

(b) operating costs relatively high

(c) hovering flying qualities problems will require extensive research and development work; the final qualities may reflect adversely on handling close to the ground

(d) interconnection of engines and propellers will pose difficult design problems

From the above it was concluded that the jet-powered aircraft, e.g. -4 and -5, were not suited well to missions like that of the Requirement. It was felt that shrouded-propeller-configurations, e.g. -3, would demand substantial research and development work without supplying adequate promise of suitability to the role specified by the Requirement.

The conclusion was made that in the deflected-slipstream and tilt-wing types – and particularly the latter – there was real promise of satisfying the Requirement and similar missions, warranting further work along these lines.

With respect to research and development work that would aid in realizing these aircraft, there are the following important avenues of investigation:

(a) Landing gear development to provide crosswind capability and very low tire footprint pressures, with low frontal area when retracted.

(b) Lightweight propellers designed specifically for VTOL and STOL application.

(c) Intensive, detailed work into optimum means of interconnecting VTOL power systems.

(d) Long-term research into integrated lift-propulsion systems for VTOL and STOL application.

(e) Application of boundary layer control and other techniques to the separated flow problems in hovering and transition flight of VTOL aircraft.

(f) Investigations into the dynamics of hovering and transition flight.

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THE CLOCK PARADOX†

by W. F. Campbell*

National Research Council

STATEMENT OF THE PROBLEM

Two years ago, in the columns of the British scientific journal *Nature*, a lively controversy broke out once again on the so-called clock paradox, first introduced by Einstein in 1905. (See Bibliography and in particular a review by Stehling of the controversy.) The paradox depends on the Theory of Relativity and the strange or unusual phenomena that result when a body travels at a velocity comparable to the velocity of light in space.

The clock paradox has led to some very interesting theoretical arguments, but now man's recent ventures into space have brought close the day when an experimental solution of the paradox may be made. Indeed it has been suggested that sufficient experimental evidence is already at hand from meson measurements made on earth at different altitudes (Crawford, 1957).

This paradox is sometimes called the Twin Paradox, but I have chosen Clock Paradox as the title because I am sure that any experimental proof in our day will involve the measurement of elapsed time intervals, differing at most by a small fraction of a second, not the comparison of colour or lack of hair, beard length, number and size of wrinkles etc. The problem will be stated in terms of twins, however, and it is assumed that clocks and biological ageing are equivalent measures of time.

Briefly, the paradox is as follows: Twin B says goodbye to Twin A on earth, enters his space ship, immediately accelerates to a velocity of $0.8c$ (where c is the velocity of light) and starts out for the star α Centauri, four light years away. On arrival he immediately turns around and heads back to the earth at the same speed. The time occupied in accelerating and decelerating the space ship is supposedly negligible compared with the time during which the velocity is steady. After his return B says the trip has taken him only six years, while A knows it has taken ten years. Are they both right? Are they still twins? This result conflicts with everyday common sense, which of course is based only on experience with much smaller velocities, but it is derived from an interpretation of Einstein's Special Theory of Relativity, published in 1905. (See Appendix for a few relevant details, and Tolman, 1934.)

The real paradox, however, comes about when we say that the same result should be achieved when we regard B as stationary, and move A (and the earth) away at a velocity of $0.8\ c$ for an equal distance and then bring him back again. Based purely on the relative motion of A and B nothing has changed, but an apparently consistent interpretation of the special theory would now have A say the trip took six years and B say ten years. Something is wrong somewhere.

POSSIBLE SOLUTIONS

One solution of the paradox is to say that the Special Theory has been misinterpreted in some way, that the problem is indeed symmetrical, and that the twins have each aged an equal number of years, namely ten. Common sense is vindicated.

A second solution states that the problem is *not* symmetrical, because large forces must be applied to accelerate B's space ship with respect to the rest of the universe, including the earth and α Centauri, regardless of whether we look at things from the point of view of A or of B. A fundamental distinction is made between the two different frames of reference. A's frame of reference is an inertial one, in which Newton's Laws of Motion hold, while B's frame of reference is accelerated from one inertial frame to another, several times. The question may be raised, however, whether favouring one frame of reference over another is in contradiction to the Special Theory.

Another solution is to say that to fully understand what happens, the time required for acceleration when A and B are far apart cannot be neglected as it is in the original statement of the problem and in the first two solutions above. That is to say the Special Theory of Relativity which deals only with uniform unaccelerated motions is not sufficient and the General Theory of Relativity, published by Einstein in 1916, must be used as well. (See Appendix, Einstein, 1918, Tolman, 1934, and Møller, 1952.)

In my humble opinion, the third solution would seem to clear up the paradox and I propose to examine it in more detail. I hope the clock diagrams will help to picture what is happening, first as seen or plotted by A, and then as seen by B. In *each* case clock A, which stays on earth, measures a greater elapsed time than does the travelling clock B.

THE THEORETICAL SOLUTION

Reference should be made to the simple clock diagrams in Figures 1 and 2. The first figure is meant to show what happens as seen by the observer on earth,

†Paper read at the First Meeting of the Astronautics Section of the C.A.I. in Ottawa on the 9th October, 1958.

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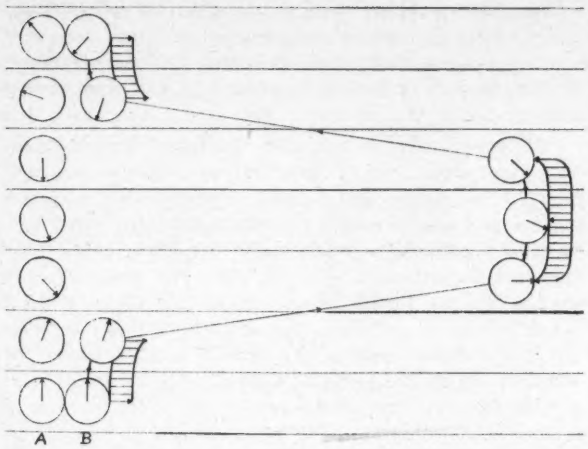

Figure 1
Trip seen from A

beside clock A. The forces required to accelerate B are seen to operate for three short transition periods of time. Since B is moving, clock B appears to be going more slowly to A, than does his own. When they come together again clock A shows a greater elapsed time, T, than clock B.

$$T_B = T_A\sqrt{1-\frac{V^2}{c^2}} \approx T_A\left(1-\frac{1}{2}\frac{V^2}{c^2}+\ldots\right)$$

What B sees from his space ship is depicted in Figure 2. In the first place, while moving at the uniform velocity, the distance to be travelled now seems shorter, and A's clock appears to be going slower than his own. For the transition periods, to preserve the same state of affairs as in Figure 1, when B experiences forces and A none, uniform gravitational fields are introduced. The velocity changes in A are thus produced by allowing it to fall freely in the gravitational field, and the same forces as before are required to maintain B at rest. When A and B are close together, the difference in their gravitational potential is negligible, but when far apart the difference causes an appreciable speeding up in clock A as seen by B.

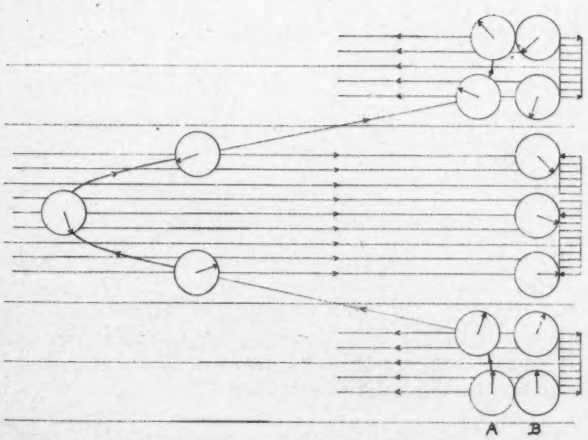

Figure 2
Trip seen from B

In this approximate treatment the gain that clock A makes over clock B in the middle transition period is enough to make the integrated time difference from start to finish the same as in Figure 1, thus removing the paradox.

$$T_A = T_B\sqrt{1-\frac{V^2}{c^2}} + \epsilon\left(1+\frac{\psi_A-\psi_B}{c^2}\right)$$
$$\approx T_B\left(1-\frac{1}{2}\frac{V^2}{c^2}+\ldots\right)+\epsilon\left(1+\frac{1}{c^2}\cdot\frac{2V}{\epsilon}\cdot\frac{VT_B}{2}\right)$$
$$\approx T_B\left(1+\frac{1}{2}\frac{V^2}{c^2}+\ldots\right)$$

which agrees with the previous result to the first order in $\frac{V^2}{c^2}$. The duration of the second transition period is taken as ϵ. As it is made to approach zero the strength of the required gravitational field becomes larger and the rate of the clock A as seen by B becomes very high, but the change in reading during this period remains the same.

Another way of picturing what happens is to draw an x vs t diagram, Figure 3, limiting ourselves to only one space dimension. Since B is in several different inertial frames of reference in succession, it is simpler to draw the diagram from the point of view of A. During B's trip, A moves up the axis of t from event S to event P with a total elapsed time of T, say. B, however, moves along two straight lines with slopes $\pm\ ^1$ respectively, passing through the event $Q\left(h, \frac{T}{2}\right)$.

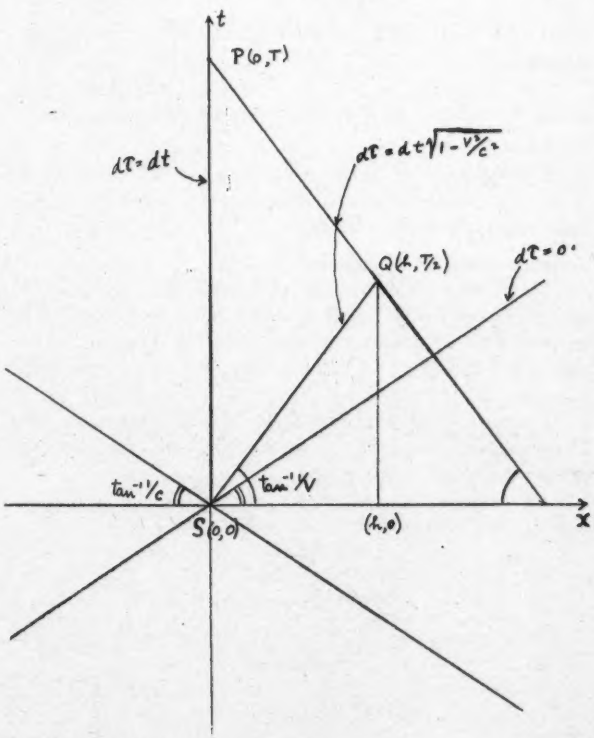

Figure 3

If this were a simple problem in plane geometry with y as the ordinate and not t, then the two different paths from point S to point P, one direct and the other through point Q, are obviously of different lengths.

$$SP < SQ + QP$$

$$\text{or } s = \int_S^P ds = \int_S^P \sqrt{dx^2 + dy^2}$$

$$s_A < s_B$$

In this case however the "proper time", the time indicated by a clock going from event S to event P, is given by the formula:

$$\tau = \int_S^P d\tau = \int_S^P \sqrt{dt^2 - \frac{dx^2}{c^2}}$$

then

$$\tau_A = T$$

$$\tau_B = T\sqrt{1 - \frac{V^2}{c^2}} < \tau_A$$

THE EXPERIMENTAL SOLUTION

There seems to be general agreement that the phenomenon of time dilatation is real, and not just an unproved theoretical concept. For example μ mesons with a known static life expectancy of a couple of microseconds have been observed to exist for much longer times when travelling close to the speed of light (Shepherd, 1952). To resolve the paradox, however, these fast moving mesons should be *decelerated* and then observed in our frame of reference. Crawford (1957) believes that such evidence of asymmetric ageing already exists.

Recent data on the accuracy of atomic clocks opens up other possibilities of experimental proof. Essen and Parry (1957) state that a clock controlled by a quartz crystal, and calibrated by a caesium resonator every few days, will provide a continuously operating clock with standard deviation of ± 2 in 10^{10}. An atomic clock should be even better. Simple calculation shows that on a satellite in a circular orbit approximately 200 miles above the earth's surface the rate of a clock should be less than an identical one on earth by 3 parts in 10^{10}. At greater distances this effect is reduced by the increase in gravitational potential. Thus for a satellite at a height of about 2,000 miles the two effects cancel. A clock on the moon should actually be fast by 7 parts in 10^{10} (Singer, 1956). For a real check on the paradox, the clock on the satellite should be returned to the earth, and that of course implies a solution of the re-entry problem.

It is obvious that some further developments must be made, but I believe we are close to an experimental verification one way or the other. Judging by the controversy already generated by the clock paradox, an unambiguous experimental result would be very welcome.

APPENDIX

SPECIAL THEORY OF RELATIVITY

Postulate 1

It is impossible to measure or detect the unaccelerated absolute velocity of a system through free space.

Postulate 2

The velocity of light in free space is the same for all observers independent of the relative velocity of the light source and the observer.

Transformation of coordinates

Two rectangular coordinates systems S (x, y, z, t) and S' (x', y', z', t') coincide at time $t = t' = 0$. The origin of S' moves at constant velocity V along the x axis in the direction of x increasing, and the corresponding axes remain parallel.

Then, it follows from the above postulates and Einstein's definition of the simultaneity of two events at different points in space that:

$$x' = \frac{x - Vt}{\sqrt{1 - \frac{V^2}{c^2}}}$$

$$y' = y$$

$$z' = z$$

$$t' = \frac{t - \frac{xV}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}}$$

or alternatively:

$$x = \frac{x' + Vt}{\sqrt{1 - \frac{V^2}{c^2}}}$$

$$t = \frac{t' + \frac{xV}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}}$$

Put in differential form, we have:

$$dx' = \frac{dx - V\,dt}{\sqrt{1 - \frac{V^2}{c^2}}}, \quad dx = \frac{dx' + V\,dt'}{\sqrt{1 - \frac{V^2}{c^2}}}$$

$$dt' = \frac{dt - \frac{V\,dx}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}}, \quad dt = \frac{dt' - \frac{V\,dx'}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}}$$

where dx, dt are taken to give the difference in the x-position and in time respectively of some given pair of neighbouring events as measured in S, and dx', dt' are the corresponding differences in S'.

Lorentz contraction

Consider a foot rule, say, of length dx', fixed in S'. To find how this length appears to an observer in S we

must consider coincidences between the end points of dx' and the corresponding points in S, separated by a distance dx. Since these coincidences must appear to be simultaneous to the observer in S, $dt = 0$, and therefore:

$$dx = dx' \sqrt{1 - \frac{V^2}{c^2}}$$

Again, if we take dx as the length of a foot rule fixed in S, to an observer in S' this length is measured as:

$$dx' = dx \sqrt{1 - \frac{V^2}{c^2}}$$

since now we must take $dt' = 0$.

Thus in each case a foot rule measures only $\sqrt{1 - \frac{V^2}{c^2}}$ ft when moving with velocity V past the observer, provided of course that the rule is held in the direction of relative motion.

Time dilatation

A time interval dt' measured by a single clock in S', between two events which occur at the same point of S', i.e. $dx' = 0$, will be measured by an observer in S as:

$$dt = \frac{dt'}{\sqrt{1 - \frac{V^2}{c^2}}}$$

In the same way a time interval dt measured in S between two events at the same point of S, so that $dx = 0$, would be measured by an observer in S' as:

$$dt' = \frac{dt}{\sqrt{1 - \frac{V^2}{c^2}}}$$

In each case the clock in the observer's frame of reference is going faster than the clock moving with velocity V past the observer by a factor

$$\frac{1}{\sqrt{1 - \frac{V^2}{c^2}}}$$

THE GENERAL THEORY OF RELATIVITY

The principle of covariance

The laws of physics can be expressed in a form which is independent of the coordinate system.

The principle of equivalence

It is always possible at any space-time point of interest to transform to coordinates such that the effects of gravity will disappear over a differential region in the neighbourhood of that point.

As a simple example of this principle, two observers, one in a uniform gravitational field, and the other in free space, each performing any given physical experiment, will obtain identical results if the observer in free space is given an acceleration relative to the non-accelerated axes of the Special Theory of Relativity, which is equal and opposite to the gravitational acceleration found by the other observer.

Gravitational potential and the rate of a clock

Imagine two identical clocks, A and B, each emitting light signals every second, say, separated by a constant distance h, and both accelerating in the direction B to A with a constant acceleration a. The time required for a light signal to pass from B to A will be, approximately, $t = h/c$.

Signals emitted from A when its velocity is V will be received at B, when B's velocity is $V + at$.

Thus an observer at B sees the clocks approaching each other, so by the ordinary Doppler principle, while receiving n_B signals from clock B, he will receive from clock A a larger number of signals, $n_A = n_B \left(1 + \frac{ah}{c^2}\right)$, approximately.

To the first order the same relationship holds if the observer is at A, since now the clocks appear to be separating.

This result, reinterpreted by the Principle of Equivalance, may then be stated $t_A = t_B \left(1 + \frac{\psi_A - \psi_B}{c^2}\right)$ where ψ is the gravitational potential.

In other words the clock at the higher gravitational potential will be observed to go faster.

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POSSIBLE METHODS OF REDUCING AIRCRAFT OPERATING COSTS†

by L. G. Randlesome*

Trans-Canada Air Lines

INTRODUCTION

THE present economic situation of low or negative margins of profit with which airline operators are faced makes it particularly important that operating costs are kept to an absolute minimum. It is believed that the ever-increasing material costs will become increasingly important to air transport economics. This problem should (and in some cases does) receive considerable attention by both the airline operator and the manufacturer.

Many of the technical pioneers of the airline industry received their initial introduction to aircraft during military duty with air commands of the various nations, with the result that airline maintenance, overhaul and inspection procedures have been patterned on military procedures. This policy, which has been revised throughout the years to take care of changing conditions, has proven to be effective and has kept the standards at a very high level. It should be noted, however, that in the Services there has always been a tendency to treat material costs as of less importance than is now becoming increasingly necessary to the airline operator. Being an ex-RAF apprentice myself, I am not attempting to belittle Air Force personnel or procedures, but am merely trying to point out an important difference between military and civil operations.

In the past, it was the general policy to condemn aircraft parts unless they looked "almost as good as new", although the airworthiness of the part was not necessarily affected. It is a human weakness to take the path of least resistance — and so, it is sometimes easier to throw a part out the window than it is to think about it and take a second look. Now that parts are becoming more expensive, it is important that we do dig in a little deeper, and do have that second look.

ACCEPTANCE STANDARDS

In some cases, parts that have shown minor defects have proven to be more reliable than new replacement parts. For example, a certain bearing was prone to a fairly high failure rate due to breakup of the inner race and, as a result, was subjected to a very critical inspection at overhaul. Failure records indicated that the majority of the service failures occurred during the bearing's first overhaul life, indicating that if the bearing survived the first overhaul life, it stood a better chance than a new bearing of surviving further overhaul lives. Based on the failure records, the overhaul acceptance standards for the bearing were relaxed and minor deficiencies of the tracks were allowed. There was no subsequent increase in the number of service failures.

This example illustrates the importance of being able to evaluate whether or not a new part would be an improvement over a used part. It is also important that the inspector should be familiar with the function of the part, as certain irregularities can be present without affecting the serviceability of the part.

Failure and scrap records are essential in order to determine the importance of a known defect. For example, if a part is usually scrapped at overhaul due to a certain defect, it would be fair to assume that considerable operating experience with this defect had been realized. Should the failure records show no failures resulting from this defect, then it is suggested that the possibility of changing the acceptance standards be investigated.

A typical example of this would be air-cooled cylinders which are subject to cracking at the spark plug bushings on a certain radial engine. A review of failure records showed that no cylinder head failures were being experienced as a result of these cracks. By recording location and length of these cracks, it was found that no propagation of existing cracks took place following the first overhaul life, although other cracks did develop. Armed with this knowledge, the overhaul acceptance standards were revised to allow cracks of limited length, with certain limits on location in relation to the spark plug bushing. This change resulted in a substantial reduction in overhaul costs, with no increase of failures in service.

SELECTIVE FIT

Cost can often be reduced by selective fit. For example, two mating parts could have a maximum permissible clearance of 0.003 in with a new clearance of 0.001 in. If each part is checked separately, so that either part can be built into any unit, the maximum permissible wear on either part would have to be limited to 0.001 in. By selective fit, either part could be used when worn to a maximum of 0.002 in, providing it is used with a new or unworn mating part.

It is appreciated that selective fit introduces the problem of keeping the parts separate when in transit between the inspection bench and the build area. It is believed, however, that the economic advantages of selective fit, especially on high-cost items, would offset any handling problems.

LIFE-LIMITED PARTS

As a result of operating experience, it is often found necessary to life-limit certain parts, usually to one or more overhaul lives. This is believed to be a good ap-

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proach on parts that are subject to failure in a certain life zone and for which primary cause of failure is unknown. These life-limited parts should not be forgotten, however, and should be sampled frequently for evidence of improvement which could result from other factors, such as changes in operating procedure, changes in lubrication system or type of lubricant, improvement in manufacture of the part, or revisions to maintenance procedures.

To quote an example, the master rod bearings of a radial engine at one time were limited to one life by a certain operator and returned to the manufacturer for reconditioning. Following a modification to the engine which introduced an improved oil pressure filter, it was discovered that the condition of the master rod bearings at overhaul was such that reconditioning no longer was necessary. In this case, the modified filter was not introduced primarily to improve the condition of the master rod bearings.

Life-limited parts that are interchangeable with other parts within a unit can sometimes be used at other locations where they are less prone to failure, without a life limitation. A good example of this is again associated with a radial engine which was subject to exhaust valve failures that occurred more frequently at certain cylinder locations. The valves in the high failure locations were limited to one overhaul life in these locations, after which they were used in other locations for an unlimited life. This system was effective in reducing the failure rate, with no increase in material costs.

REPAIR SCHEMES

Substantial reductions in material costs can often be made by suitable repair schemes. These are usually taken care of by the manufacturer, but should be reviewed by the operator, with new schemes recommended and introduced as experience dictates. Before introducing a repair scheme, however, (even if recommended by the manufacturer) a very careful economic analysis should be carried out. This should include cost of the repair, cost of the part, whether or not any other life-limiting factors for the part exist, and the expected life of the part following the repair.

For example, a part costing $500 new, if found defective at the end of its fifth overhaul life, would not warrant a $100 repair if scrap records indicated that the average expected life of the part was six overhauls due to some other weakness in the part for which a repair was not feasible. If no other life-limiting factors are apparent, then generally speaking the economics of such a repair would be sound, providing the repair "builds in" sufficient additional life to repay its cost.

As the cost of a possible repair is often difficult to forecast accurately, it is suggested that, prior to a repair being adopted, a prototype of the repair be carried out so that both the cost and quality of the repair can be assessed accurately. When dealing with repairs to more critical parts, it is suggested that a few of the repaired parts be released to service on a "type trial" basis, which would permit evaluation prior to the introduction of a general repair scheme.

Sometimes it is found that repaired parts give better service than new ones. For example, worn shafts which have been plated to restore the shaft to its original size often have better wearing qualities than the original shaft. In addition, repairs to cracked parts by welding could result in life improvement due to release of stresses within the part.

With improved welding techniques, it appears that welding of high-cost, light alloy engine castings will be a good area for reduction of material costs. The quality of a weld can now be reasonably well determined by radiographic inspection. One of the major problems with welding is distortion of the part, and further development to improve this condition is necessary.

Defective parts for which repairs are authorized should be processed as fast as possible. This will cut down the cost of replacement parts and ensure that full use has been made of the part prior to possible obsolescence.

DESIGN

It is thought that the manufacturer could sometimes reduce replacement costs of some high-cost items by design action. For example, an integral gearwheel and shaft is possibly scrapped due to breakup of the gear teeth. If these parts could be separated, then only the gear would have to be condemned. Often expensive shafts are designed with an integral bearing inner race. If such parts were designed with a separate bearing race, then only the bearing, if defective, would have to be replaced. It is believed that, in some cases, the slight weight penalty, if any, would be offset by the economic advantages.

CONCLUSIONS

To sum up, it is believed that considerable savings are possible by changing acceptance standards and introducing repair schemes as found necessary and possible in the light of new experience.

In order to do this effectively, it is necessary to keep accurate and up-to-date records of failed and condemned parts, showing cause for rejection, time since overhaul, and total time of the part. Condemned and failed parts should be examined (possibly on a sampling basis) by qualified personnel in order to evaluate the possibilities of a repair scheme or change in acceptance standards. At the same time, any new failure trends should become apparent and this knowledge can be used to trigger investigations into possible failure areas. It is suggested that these personnel have an unbiased outlook, with no strings attached to other groups except perhaps for administrative purposes.

It should be borne in mind that changes should only be made consistent with a safe and efficient operation, and that Department of Transport requirements continue to be met at all times.

ACKNOWLEDGMENT

This article is based on experience obtained in the Royal Air Force, Canadian Pacific Air Lines Ltd., Trans-Canada Air Lines and the Royal Canadian Air Force (Reserve). It should be pointed out that the opinions expressed by the writer are not necessarily shared by the organizations with which he has been or is presently employed.

ALUMINUM CORROSION — AN UNNECESSARY EVIL†

by J. R. Beale*

Aluminum Company of Canada, Limited

ALUMINUM has now had nearly three-quarters of a century of use. It has demonstrated its ability to withstand the normal attack as a building covering as well as the relatively hard life of a kitchen utensil. A building in Montreal erected before the turn of the century still wears the original aluminum cornice.

The early material contained only impurities that were inherent to the smelting process. This metal, although good enough for its use then, would not have been attractive strengthwise to the aircraft industry. With the addition of small percentages of copper together with proper heat treatments, the yield strength was increased tenfold. But metals were now combined which, in the presence of moisture, would set up on the surface many local galvanic cells with resulting corrosion. Basically, if we could seal off all surfaces from contact with any electrolyte, there would be no corrosion. Practically this is impossible and, in many cases, unnecessary as all fluids which might be an electrolyte are not damaging.

CLADDING

The first major step by the aluminum producers was to clad the copper constituent sheet with pure aluminum. This served a twofold purpose. First of all, it presented a more resistant surface to attacking elements. Secondly, if the cladding were scratched or broken, which it always is at a cut edge, attack would be confined to the cladding. Protection will be afforded bare core metal up to distances of about ⅛ of an inch.

The other high strength alloy group is the aluminum-zinc-magnesium-copper family of which 75S is the most common. Pure aluminum cladding will not protect this alloy. However, by adding 1% zinc to the pure aluminum cladding the new material — 72S alloy — will protect 75S.

Cladding has only appeared in rolled sheet products. Recent developments have shown that it is feasible to extrude from a multi-alloy billet and produce clad tubing. The lack of uniformity of cladding still excludes the use of such material for aircraft structures, but some day it may be possible to extrude some form of cladding protection in a bialloy shape. In very special cases, partially clad forgings have been produced.

†Paper read at the Mid-season Meeting of the C.A.I. in Vancouver on the 28th February, 1958.

*Senior Engineer, Sales Development Division.

EFFECTS OF HEAT TREATMENT

Alclad sheet brings up the problem of heat treatment. Reheating of alclad materials causes a diffusion into the cladding of the alloying materials. Thus, in 24S Alclad, the cladding can become so rich in copper that there is no longer enough potential difference between core and cladding to give sacrificial galvanic protection. This is the reason that specification MIL-H-6088A prohibits more than one solution heat treatment of all clad materials below a thickness of 0.125 in. Material that requires more forming than is possible with fully heat treated 24S should be purchased in the annealed condition and solution heat treated immediately before forming. This is acceptable within the above specification.

Most of you know that optimum mechanical and corrosion resistance properties are attained by a rapid cold water quench after solution heat treatment. Conversely, a slow quench not only lowers properties, but decreases the resistance to corrosion, especially in unclad copper alloys. The delay permits a heavy precipitation of copper constituent at the grain boundaries alongside a copper depleted aluminum matrix. In the presence of moisture a galvanic cell is set up which dissolves the aluminum along the grain boundaries as this area is anodic to the body of the grain. This is called intergranular corrosion and is illustrated in Figure 1.

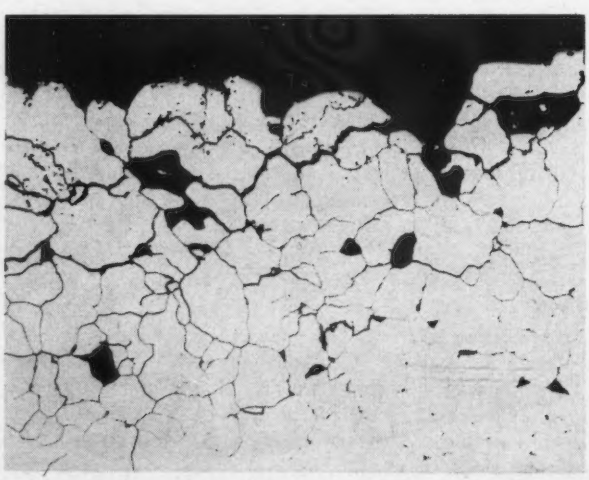

Figure 1
Intergranular corrosion

A delay of forty seconds has shown a percentage drop to 65% of tensile strength after accelerated corrosion test as compared with a normal rapid quench. 75S and 65S do not exhibit this condition to the same extent.

Stress corrosion

In aircraft alloys of the 24S and 75S type, high stresses accelerate the tendency to intergranular corrosion and this is known as stress corrosion. The condition may develop in large forgings. In order to minimize quenching stress after solution heat treatment, hot and even boiling water is used. This in itself might tend to lower corrosion resistance due to the lower rate of quenching. Residual stress, as in quenched forgings, can be as high as ⅓ of the yield strength. It will be found as a compression stress on the surface and a tensile stress toward the centre.

During machining the outside is removed leaving a tensile stress area exposed. If the total stresses in use (residual and applied) are enduring and between ½ and ¾ of the yield strength and the environment is corrosive, stress corrosion may result[1] (Figure 2).

To avoid this condition the maximum amount of machining should be done before heat treatment so that the outside of the forging will remain a compression stress area. Compressive stresses do not cause stress corrosion. Also, as the section becomes smaller, the residual stresses due to quenching are not so great. Internal stress can also be created by cold forming. To avoid this, cold forming should be done prior to heat treatment or soon after quenching. In the case of 75S it should be done within two hours of quenching. Arblaster[2] reports a case of a 75ST6 spar that was bent some time beyond the two hour figure and touched by a workman's foot, whereupon the spar cracked with the report of a pistol shot.

The design of assemblies should avoid introducing high permanent tensile stresses, since these act in the same way as residual stresses. An example would be a pin joint in which the pin has been cold shrunk and the edge to hole distance is small, leading to a high stress from the hole to the edge. The repairing of a riveted structure joint might produce the same result.

From a practical viewpoint the above theories have been investigated to provide answers for a relatively small number of actual failures in service. If attention is paid to the keeping of residual and permanently applied stresses to a minimum in design, heat treatment, fabrication, and assembly, then stress corrosion failure in aircraft service may be avoided even when using alloys that are considered to be susceptible to stress corrosion. Actually, such cases are rare.

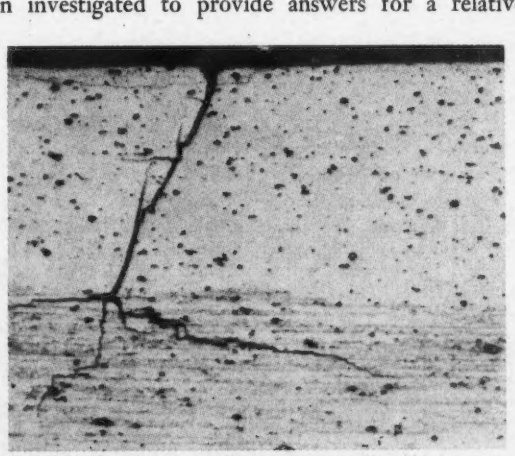

Figure 2
Stress corrosion crack

Other heat treatment effects

Examination of a heat treat temperature table shows marked differences for various alloys. Also, a tolerance of ±5°F is indicated. Let us take 24S and 26S as examples. 24S is solution treated between 915°F and 925°F including the tolerance, whereas 26S uses 935°F to 945°F. If the higher temperature were used for 24S, incipient fusion of the copper eutectic would take place. The damage is so great that the metal can only be put back in the melting pot.

This fault can arise from hot spots in a furnace. Sufficient pyrometric surveys with and without a load should be made in the heat treatment furnace to insure uniformity within the specified temperature limits. The same care must be exercised in melting aluminum for castings. It is amazing how many small foundries still melt by guess rather than by pyrometric control.

High temperature oxidation is another consideration in heat treatment. It is observed as a severe darkening of the aluminum surface and blisters within the metal itself. Microscopic examination shows the damaging attack down through and around the grains with voids formed by gas pockets. The causes are high atmospheric moisture from quench tanks, either as steam or from moisture picked up as extrusions are lowered into the quench tank prior to being drawn up into the furnace (Figure 3).

Figure 3
High temperature oxidation, AL. MG. alloy, two surfaces mounted face to face

The presence of sulphur from oil and gas fired furnaces, as well as lubricating and cutting oils, acts as a catalyst, increasing the condition. The use of sodium fluoborate compounds in the furnace acts as a protective atmosphere, thus preventing the attack. Bare 24S and 56S particularly need the protection. The use of the protective compound can increase the difficulty of spot welding due to the nature of the surface film produced.

Salt baths used for heat treating generally use a combination of sodium nitrate and sodium nitrite. The addition of the latter lowers the melting temperature. However, when the nitrite content is high, there may be a tendency to intergranular corrosion. This can be offset by the addition of a small quantity of dichromate to the salt bath. Salt bath residues should be removed after quenching and, if followed by a conversion coating or anodizing, no corrosion should take place as a result of the salt bath immersion.

FRETTING CORROSION

Fretting corrosion is a North American term. In England it is called "black spot" or "electrostatic burning". It first appeared in the aircraft industry in packs

of sheet en route from producer to user. It shows up in the form of small black spots which, when examined under a low power glass, show black specks in highly polished craters. The latter look as if they had been created by melting by an electric spark. Actually, such a spot will be a contact point between two sheets which have a slight slipping motion during shipping. Aluminum oxide is found at the point of contact which now acts as a grinding medium to create the crater. Tightly banding the pack to prevent slipping generally eliminates the problem. Tissue interleafing and oiling are also beneficial.

The same condition can take place in a fitting that is not tight enough to prevent motion. The problem can also occur in tubing and extrusions unless tightly packed. A recent occurrence was found in a shock leg where the sliding bearing was machined from an aluminum bearing alloy casting. The tolerances permitted an almost interference fit. Due to a scraper ring there was no lubricant on the sliding bearing surface. Black spots appeared on the bearing which coincided with scratches on the chrome plated leg. This was a form of fretting corrosion.

CREVICE CORROSION

Crevice corrosion may occur where a faying surface permits the capillary ingress of the crevice to its innermost point (Figure 4). Pitting develops just inside the crevice where the metal is in contact with water depleted of oxygen, thus creating an anodic condition relative to the mouth of the crevice where the water is saturated with oxygen.

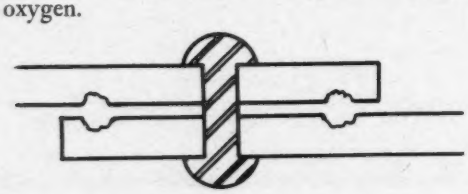

Figure 4
Crevice corrosion

Crevice corrosion can be avoided by design elimination of crevices that will trap moisture, or by filling those that cannot be avoided with an inhibiting jointing or sealing compound.

FUEL TANKS

Piston aircraft use fuels to which an anti-knock ingredient – tetraethyl lead – has been added. Over the years it has been established that dry fuel does not corrode aluminum tanks. However, in the presence of water, pitting can take place. The water can contain heavy metals gathered en route to the fuel tank, as well as from the anti-knock compounds. The sump should be regularly drained, and when the aircraft is put into storage for long periods it is advisable to drain the tank and the sump[3, 4].

Tank designers should avoid crevices and pockets which do not have free drainage to the sump. When repairs are made to a tank, similar alloys should be used. Cases of corrosion have been found of a 2S alloy being combined with 24S. Now cathodic protection in the presence of moisture takes place at the expense of the 2S.

While speaking of fuel tanks, hold down straps, felt pads and water absorbent gasket materials have given trouble in becoming wet. This is another case of oxygen variation similar to crevice corrosion. Inert non-absorptive materials should be used. Otherwise inhibiting materials, such as zinc chromate, are necessary.

Fuel tanks, repaired by gas welding in the field, have corroded due to improper flux removal after welding.

EXHAUST GASES

Fuels naturally lead to exhaust gases. With the identification of lead bromide in areas where exhaust gases contact aircraft surfaces, laboratory investigations[5] were carried out to determine the possible action on such surfaces. It was established that when dry, there was no attack on aluminum. However, in a moist atmosphere, a self-propagating cycle was shown of lead bromide, hydro-bromic acid, aluminum bromide, aluminum hydroxide back to hydrobromic acid. In areas of high relative humidity an adequate cleaning schedule is necessary to control the situation. Considerable work is reported in an endeavour to develop a coating that will form a barrier. The epoxy resins give good promise for this.

The use of rockets, either in military aircraft or for takeoff assistance, produces a corrosion-producing contaminant in the form of chlorides from their exhaust. Chlorides and moisture form hydrochloric acid. Immediate washing down removes the products. If this is impracticable, a coat of spar varnish will provide protection.

COOLANT

Triethanolamine phosphate was used as a corrosion inhibitor in ethylene glycol coolants. A study by Thompson & Losking[6] showed that any copper ions picked up in the system remained stable until they contacted aluminum or iron surfaces, where they were deposited, causing localized corrosion.

WOOD

Certain kinds of wood are not compatible with aluminum. This is in addition to the moisture holding properties with a consequent oxygen screening. If the wood is thoroughly seasoned and stays dry in service there is no problem. The latter is almost impossible. Therefore, a barrier of bitumen or other electrically neutral material should be used. A study carried out in connection with the Royal Canadian Navy ship building programme showed the order of corrosivity, from the greatest to the least, as follows:

Gumwood, Douglas Fir, Mahogany and Rock Elm.

Other investigations showed California Redwood and Western Red Cedar good, while Oak was bad. Wood preservatives have been studied. Those containing coal tar, creosote or certain chromates have been proven to be harmless. On the other hand, those containing copper or mercury should be avoided.

DISSIMILAR METALS

Dissimilar metals in contact, in the presence of moisture, have always been recognized as a possible source of corrosion. Metals can be arranged in a galvanic series for any particular environment. In this series any metal above another is termed anodic and has a tendency to galvanically corrode when in contact with a lower, which is called cathodic. The cathode does not corrode.

The farther apart in the series, the greater the tendency toward galvanic action. However, the *amount* of severity of galvanic corrosion depends on the following factors:

(1) Electrical resistance of current path—
  (a) due to film on metal surface
  (b) due to conductivity of electrolyte solution
  (c) due to distances between surfaces
(2) Relative anode and cathode area
(3) Polarization

If a complete barrier is erected to prevent the electrical current flow from one piece of metal to the other, no galvanic corrosion can take place. This is done by using one or more of the following: an inert gasket, such as rubber; inhibiting paint; materials, such as zinc chromate primer or caulking compounds. Instead of a barrier one of the metals can be plated with metal that is closer in the series to the other and thus the tendency to galvanic action is less. Thus, a brass part is cadmium plated when assembled to an aluminum part.

SPILT ACIDS

Battery acid can be a problem. Designers try to provide overflow pans but, despite this, spilling and boiling over on overcharge may allow electrolyte to reach bare aluminum. The safest action to take is to wash with lots of water. Neutralization with ammonia is permissible but not with other alkalis. Rinsing with a 10% solution of hot chromic acid, although it does not neutralize any remaining sulphuric, will act as an inhibitor to possible corrosion.

Pilot relief tube spray on service aircraft has caused trouble, mainly through lack of adequate cleaning of the areas concerned.

SHOP PROCESSES

In aircraft plants many liquids are used during processing operations. Cutting oils and forming compounds which are satisfactory for other metals may be corrosive to aluminum. Plants with wise metallurgical control will prove all such materials before allowing their use.

Cleaning, degreasing and paint stripping materials fall into the same class. Many of the latter are strongly alkaline. These not only attack paint, but aluminum as well. One sad experience is recalled where a group of painted landing gear parts, being reconditioned, had the working surface areas reduced in dimension to such an extent that the parts had to be scrapped.

Trichlorethylene degreasing fluid, plus moisture, can break down with the formation of hydrochloric acid which will seriously attack aluminum parts dipped in the solution. Inhibitors are added to help prevent the breakdown. The tanks should be cleaned regularly, as dirt and metal chips also act as a catalyst in the acid formation.

Castell[7] reports a corrosion possibility when machining large wing panels using a vacuum hold down plate on the milling machine. The coolant became an electrolyte between the 75S alloy section and the steel vacuum plate. Pitting took place which could become intergranular. The amount of corrosion was reduced by cadmium or zinc plating the steel plate. An aluminum vacuum plate would eliminate the problem.

EFFECTS OF TEMPERATURE

At first glance temperature acts in a paradoxical way. An increase in temperature has a strong accelerating effect on corrosion. However, in some cases the heat will have a beneficial effect, speeding up drying. The heat capacity of a metal surface can affect the corrosion rate. When an unpainted aluminum aircraft is left outside and poorly maintained, the pitting of the skin will first appear under the wings. The mass of the wing structure with its gasoline tanks and wing parts causes the under surface to have a lower rate of heating and cooling. On an average morning as the air temperature rises, the lower surface remains cooler than the rest of the skin and retains a film of dew or condensation for a longer period. This effect has been demonstrated by exposing outdoors two panels of aluminum in a horizontal position, one with a large block of aluminum on top and one without. After a year it was evident that pitting was more severe on the under surfaces of the sheet beneath the block than on the other sheet, although the specimens were side by side.

ANODIC TREATMENT

Aluminum owes its normal long life to a natural coating of aluminum oxide. This is very thin – in the order of less than a millionth of an inch. An electrochemical process in which the aluminum part is made the anode, usually in an acid bath, causes the oxide coat to become thicker. The process is called anodizing. Many chemicals are used for the electrolyte, but the two most common are chromic acid and sulphuric acid. For equal thicknesses of oxide coating the chromic acid method is the most resistant to corrosion. However, in actual practice, the sulphuric acid method produces a much thicker coating. Therefore it can be said that it provides the better resistance. If an *assembly* has to be anodized, chromic acid is a must, because any trapped chromic acid between the faying surfaces will act as an inhibitor, whereas entrapped sulphuric acid will eventually attack in the hidden areas. Proper sealing is part of the anodizing process. Checks are required to ensure this has been accomplished. Although hot water is the normal sealing medium, where maximum corrosion resistance is required, chromates are added to the sealing bath. Alloys containing over 4½% of copper should not be anodized in chromic acid, as intergranular corrosion may take place. Specification DTD 910 states this as a requirement. Parts should never be in a sulphuric acid anodizing bath without the current on, otherwise undesirable attack will take place.

Hard anodizing, such as Martin Hard Coat, is a relative newcomer to the anodizing field. Its very dense and usually thicker coating provides an excellent friction wearing surface. Examples of use are the main leg member of the Avro "Vulcan" bogey undercarriage, cordite cartridge containers in gas turbine starters, and abrasion strips. Wernick and Pinner[8] point to the fact that the thicker coating obtained by this method does not necessarily give better corrosion protection, as it contains micro cracks which act as capillary entry points for moisture. Further, they state that 24S Alclad gives the best resistance after hard coating. 65S, 75S Alclad and bare follow, with 24S bare at the bottom of the list.

CONVERSION COATINGS

In the last few years a new type of protection has become much used. This is the group called conversion coatings. Chemical baths change the outside surface to an aluminum compound that is more inert. Inhibiting materials are often included. These proprietary treatments are mainly developments from the earlier prepaint use of phosphoric acid. Some trade names are – Alodine, Iridite and Bonderite. These names carry a type number as certain solutions are developed for a special method of application on certain metals. By themselves they are relatively soft with low abrasion resistance. However, with an overcoat of modern tough paint materials, they do an excellent job of corrosion resistance. Work done in our laboratory shows that painted samples, properly prepared and scribed to bare metal, will stand 10,000 hrs in a salt spray chamber without any paint removed.

The same result was obtained using anodizing instead of the conversion coating as the prepaint medium. We believe the anodizing to be slightly superior. However, as aircraft components become larger, definite advantages start to favour the conversion coatings. The equipment cost is much less. A small local repair can be done to a conversion coating, whereas the whole part has to be reanodized – a much costlier operation. No electrical connections in racking, long lasting baskets instead of special anodizing racks, shorter overall processing time and lower manpower requirements are further attractions.

STORAGE AND HANDLING

During the war years much educational work was carried on with aircraft plants on sheet storage. It should be kept in dry, even heat storage. If moisture laden warm air is suddenly chilled by cold metal, condensation results. The moisture forming between sheets will cause a surface attack called "water stain". Sheet material should be stored on edge rather than in the flat. This not only gives a better chance for air circulation but makes it easier to use up first delivered sheet first. Clean, dry cotton gloves are worthwhile for sheet handlers putting material into storage, especially in warm weather. Aluminum sheet should be lifted to and from a pile rather than slid over. A sharp edge can scratch deep into the cladding. Although in the 24 and 26S type alloys such scratches do not increase the corrosion problem, in 75S they do. Here they may lead to stress corrosion failures.

MAINTENANCE AND CLEANING

Major H. E. Smith of the U.S. Air Force wrote a report entitled "Corrosion is no Accident"[9]. It concerned eighty C47 aircraft at the Biak Air Depot in the East Indies. Neither length of time in the area nor flying time, tied in with reasons that thirteen of the eighty were repairable, while the balance were scrapped. He states that, despite inspection, detection and prevention of corrosion being thoroughly discussed, and correction procedures being set down in applicable aircraft manuals and orders, the cause of the trouble was definitely determined to be lack of proper maintenance and inspection. The small amount of flying time and the uniformity of corrosion evidenced, regardless of the amount of time they were exposed to the moisture conditions of the area, plus the small amount of corrosion on a few aircraft where maintenance had been acceptable, gives definite grounds for this statement.

Aircraft can be painted as a corrosion prevention. This imposes a weight penalty. A coat of spar varnish or non-yellowing clear metal lacquer will prevent pitting on surfaces that do not get a frequent cleaning. However, many of the airlines believe that an aircraft surface frequently and regularly cleaned will retain its original good, shiny metal look. Some cleaners are slightly abrasive and during the operation deposit a thin coating of silicones and carnauba wax. These latter materials extend the cleaning time by forming a barrier to atmospheric grime and soil. Don't forget that cleanliness doesn't stop at the outside surface, but needs to be carried into flap wells, undercarriage parts, inside components that are not sealed, and many other hidden areas.

In closing I would like to say that no other industry reports to us so few corrosion problems. Therefore, basically, the designers, manufacturers and operators know how to avoid corrosion and, when it does occur, someone has not followed the rules.

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C.A.I. LOG

SECRETARY'S LETTER

IAS/CAI MEETING

ANOTHER IAS/CAI Meeting has come and gone. Because this Joint Meeting is regularly held in Canada and because we always include it as a major event in the CAI calendar, there is a tendency for local Canadians and visiting Americans alike to regard it as a CAI show. Believe me, it is a joint effort in every sense, as anyone who can see below the surface will readily appreciate. The IAS handles most of the printing, including the production of the preprints which is a very costly and laborious business. The IAS sends up staff to help and guide us. And for months beforehand, IAS and CAI Headquarters are working closely together in the arrangement of speakers and all the other details.

We may be the hosts on these occasions but let us recognize what very helpful guests we have. The first major meeting we ever held was the IAS/CAI Meeting of 1954. The IAS showed us how – they are still showing us how – and we must never forget the debt we owe them.

OCTOBER 1959

Next year, as has been announced already, the IAS/CAI Meeting will be replaced by the Anglo-American Conference, in which the CAI will be participating for the first time. No doubt it will retain its name, as it should, but in 1959 it will contain an element which is neither Anglo nor American but perhaps a combination of the two. The sessions of the Conference will take place in New York and Canadian papers will be included in the programme. Thereafter the delegates will tour sundry plants and establishments on both sides of the border.

It will be good to have the British with us. The RAeS has always been most helpful and has taken a great interest in our annual meetings with the IAS. Dr. Ballantyne's cable referred to on page 329 is indicative of the manner in which they follow our programme; it was a very nice gesture.

FILM LIST

The Film List that I have been fussing about for the last two years is at last available. It is a slim volume admittedly, but it is a start. We make no apologies for its slimness because it has been our aim to produce a list of good films of current interest, and we shall reissue the list from time to time, weeding out the films that have lost their immediate usefulness and, I hope, introducing new ones. As a matter of fact, since we went to press with this list, we have received particulars of three or four films that would have been included had we known of them earlier. They will be included in the next issue.

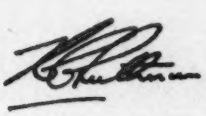
The preparation of this list is a continuing process and I hope that members who have been sending us information about films will not relax their efforts now that the first issue is published. There will always be the demands of the "next issue" to be met.

STUDENT AWARDS

Members will be interested to know that a scheme of student competitions and awards, introduced by the Council earlier this year, is now beginning to take definite shape and will be in operation in the present academic year. Under the scheme each Branch is responsible for organizing competitions at the various educational institutions within its area and several Branches have already submitted their proposals for Council approval. I hope in due course to be able to publish details of each competition in the Journal.

The scheme is intended to promote an interest in aeronautical engineering among senior students and I think it important that all members of the Institute should take a lively interest in the competitions run by their respective Branches. There should be a good turnout of Branch members at each prize-giving ceremony and in every case where the competition involves the presentation of student papers to Branch meetings. We should make these students welcome into the profession which we hope they will have chosen as their own.

The Council's intention is that when these Branch competitions have been in operation for a little while, a national scheme leading perhaps to scholarships and bursaries will be introduced by the Institute.



During Recess

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Table
Reception

1958

I A S
C A I

Preprints and Registration

I.A.S. and C.A.I. Officers

The audiences at two Sessions

JOINT I.A.S./C.A.I. MEETING

THE annual Joint Meeting with the Institute of the Aeronautical Sciences took place on the 7th and 8th October at the Chateau Laurier, Ottawa. The programme included seven technical sessions; some people complained that they were all too specialized and others congratulated the Programmes Committee for a series of papers of rather higher technical level than usual! Whatever the viewpoint, the attendance was fairly satisfactory with a registration of 358. Reports on the technical sessions appear later.

THE DINNER

The Dinner, held on the first day, was attended by 503 members and guests. Once again it gave great pleasure to the members of the C.A.I. that the President of the I.A.S. was able to be present at this Joint Meeting. Mr. E. C. Wells had come all the way from Seattle for the occasion. Other I.A.S. Officers at the Head Table at the Dinner were Dr. E. R. Sharp, Past President, Mr. S. P. Johnston, Director, and Mr. R. R. Dexter, Secretary. Dr. G. N. Patterson, President of the C.A.I., was in the Chair.

In his opening remarks Dr. Patterson read the following cable from Dr. A. M. Ballantyne, Secretary of the R.Ae.S.:

> "The President and Council of the Royal Aeronautical Society send greetings to the Canadian Aeronautical Institute and the Institute of the Aeronautical Sciences for the success of their 1958 Joint Meeting."

On behalf of both Institutes, Dr. Patterson expressed his thanks to the Royal Aeronautical Society for its kind message. Dr. Patterson also mentioned that the coming year would be the 50th Anniversary of flight in Canada; he pointed out that the first flight, in 1909, was in itself a joint endeavour by the Canadian and American members of the Aerial Experiment Association and that this spirit of cooperation had existed ever since.

Mr. Wells referred to the recent International Congress in Madrid and said that history was being made in the field of international relations. Worldwide understanding was being developed from such traditions of cooperation as those on which this series of I.A.S./C.A.I. Meetings was based.

The two Presidents were followed by the Principal Speaker, General E. R. Quesada, Chairman of the U.S. Airways Modernization Board. In his introduction of General Quesada, Dr. Patterson also announced that he had very recently been appointed Administrator of the new Federal Aviation Agency and he congratulated him on this appointment.

Mr. H. H. Kelland, Chairman of the Ottawa Branch, welcoming members to the first session

Gen. E. R. Quesada, Principal Speaker, with Dr. G. N. Patterson, President CAI, and Mr. E. C. Wells, President IAS

Unfortunately it is not possible to print General Quesada's address in full. Its title was "Research and Development Essential to a Common Air Navigation System" and the General gave a broad review of the plans being made to bring the United States airways up to the same stage of development as that already attained by the other branches of aeronautical engineering. He pointed out that a dynamic and realistic programme of research and development was necessary. A five-year plan had been set up, to give a cut-off date, and the first step was one of analysis, to define scientifically rather than intuitively the requirements that must be met. Thereafter a series of programmes had been laid out, to develop automatic air traffic control, to improve communications and so forth. Atlantic City had been selected as the centre of this operation because it lay close to the New York-Washington airway, with its very dense traffic, and experienced a wide variety of weather conditions.

General Quesada recognized the importance of a common solution to the

problem and said that a member of the Canadian Department of Transport was working with his own organization. He promised to keep the Canadian authorities fully and frequently informed.

In an address of thanks, Mr. J. R. Baldwin, Deputy Minister of Transport, said that General Quesada's programme was one of very great promise; something was going to be done and he was confident that the General would play a leading role in the development of aviation within the next few years. He welcomed his very concise statement of his objectives and the methods to be adopted in achieving them.

Aeromedicine Session: (l to r) Dr. A. W. Hetherington, Dr. C. P. Seitz, Dr. M. G. Whillans and G/C W. R. Franks (Chairman)

TECHNICAL SESSIONS

Members of the Ottawa Branch have reported as follows on the technical sessions:

Morning Sessions, October 7th
(Two Sessions running concurrently)

AEROMEDICINE

Reported by W/C D. O. Coons

This Session was under the chairmanship of Group Captain W. R. Franks, Scientific Adviser in Aviation Medicine, RCAF Institute of Aviation Medicine. He welcomed the opportunity to chair this Session and observed that in a sense this was a pioneering effort to devote an entire session to the presentation of scientific papers on subjects of aeromedical importance.

The first paper, entitled "The Design of Training Equipment" was presented by Dr. C. P. Seitz, Chief Human Engineer of Grumman Aircraft Engineering Corp. He started by emphasizing the importance of training since in a competition of equipment of almost equal technical qualities superiority would depend on how well the equipment was used. He went on to point out that the training problem must be defined before the training equipment could be designed effectively and simply. A short film was shown to supplement the speaker's description of the application of training aids through the five phases of learning – the idea, trial, practice, integration and review. In closing, Dr. Seitz urged all training device experts to give honest opinions on training requirements and not necessarily to "give the customer what he wants".

In the ensuing discussion, Dr. Seitz was asked if complex trainers and simulators do not stimulate motivation to learn by their realism and he replied that, when there is little to choose between complex and simple devices, the more complex can fail, thereby tending to increase the requirement for maintenance. It has, therefore, been concluded that a complex device is not necessarily the best aid to have. It was emphasized that the most important factor – the stimulation of motivation to learn – was the enthusiasm with which instructors "sold" the equipment to the students.

The Chairman observed the timeliness of the talk and complimented Dr. Seitz on his courage. He stated that he had recent occasion to learn that millions of dollars have been and are being spent on training devices for new aircraft; and he pointed out that the real crux in training is to teach experienced people to forget "old tricks".

Dr. M. G. Whillans, Assistant Chief Scientist and Director of Biosciences Research, DRB, spoke on "Functional Mock-ups for Aircrew". His theme was that time and money would be saved if instead of the current practice of a brief view of a mock-up, the mock-up should simulate crew environment in considerable detail and that aircrew personnel should be put through several work/rest routines in it. He illustrated his points by describing a hypothetical development programme which he called "Odysseus". The speaker was asked the estimated cost, in dollars and time, of his hypothetical case and replied that he could not see it being more costly than the regular development programme.

Dr. Seitz entered the discussion, emphasizing that the human factors people must get in on a project early and Dr. Whillans added that a group in touch with daily development problems and in a position of knowledge through experience and study should be available to give advice on a full-time basis.

At this point Dr. Hetherington observed that the industry was prone to rely on the universities and Service laboratories for information in this field. He pointed out that these services are too often geographically remote and, therefore, not as readily accessible as would be desired. He suggested it is necessary for the industry to use bioscientists within their own houses to help in translating the available information into a form which is usable by the technical personnel.

Mr. D. H. Rogers pointed out that the systems of the Arrow and Caribou were the result of a cooperative effort between the Companies, Defence Research Board, and the RCAF scientific facilities at IAM, CEPE and others.

The Chairman referred to efforts which had been made to establish a source of human factors or bioscientific advice in the RCAF. Group Captain Brown, Deputy Director General Medical Services (Air), confirmed that efforts are continuing to be made in this area.

The final speaker was Dr. A. W. Hetherington, Technical Director, Directorate of Life Sciences, ARDC, USAF, and his paper was entitled "Recent Studies of Human Requirements in Hypersonic Escape". He started by explaining that although USAF experience in supersonic escape had been unexpectedly good it could not always be extrapolated into the hypersonic regime. He outlined the problem and said that to meet the requirements the capsule concept had been adopted and he described the avenues of development that were being explored. On the subject of human tolerances, Dr. Hetherington gave an account of some of the results obtained from tests and from recent work on the rocket sled.

In the discussion Dr. Hetherington was asked if a linked escape system had been considered for multi-placed aircraft and replied that, although Canadian development had been watched with some interest, some concern had been

felt for the reliability of the system; for example, the captain had to make the first move in the escape sequence and he might be incapacitated. In answer to another question, Dr. Hetherington said that it had always been part of the design study to provide separate cocoons or capsules for each crew member in multi-place aircraft and at present the tendency is towards separate, individual pods.

As regards USAF philosophy on extending the requirements to provide for escape outside the flight envelope, the speaker said that, though some extra dividends in the design of an escape system were always expected, dividends in this area might carry a reduced assurance of "safe" escape.

Asked to amplify what he had said in his paper about the protection afforded by insulated suits, Dr. Hetherington said that the integration of flying clothing was not completed but improvements in flexibility, mobility and weight seemed likely to compromise insulation, vapour barrier etc.; reliance for protection from heat is placed on ventilation.

In closing the Session, the Chairman thanked the speakers and observed that the lively discussion after each paper was a vindication of the efforts of the planners in setting up this part of the programme.

AEROELASTICITY

Reported by A. H. Hall

Under the doting eye of Chairman B. J. Kaganov, skeletons in the aeroelasticity closet were again rattled in a fundamental mode by four able dynamicists.

The evils of flutter, divergence and loss of control have been recorded for over five decades and, while aeroelasticians have not been altogether successful in avoiding those evils, they look back on a proud heritage and face the future reassured in the knowledge that no accident has gone unexplained. The road has not been easy. At times, the game has been disowned by both aerodynamicists and structure engineers alike. But with the welding of these phenomena into a solid scientific discipline – aeroelasticity – the difficulties were surmounted, and the responsibility was placed squarely on the shoulders of aeroelasticians. From time to time, representatives of this august fraternity foregather to exchange notes and examine their progress. It was such an occasion at the Chateau Laurier.

Presentations and discussions were interesting, informative, and certainly did not want in vitality, and when the meeting was over one felt that the morning was well spent. There was a theme running through it all, which is best elucidated by the experts, who speak for themselves as the curtain is raised on an appropriate setting:

J. McKillop (entering with the remnants of a completely tested flutter model under his arm): But you have to remember that we're not testing the structure – we're trying to find out something about the aerodynamics.

W. P. Targoff (unravelling a roll of punched tape by matrix iteration procedures): It is believed that the method can be easily applied by inexperienced personnel, once the physical properties of the wing have been determined.

R. A. Boorne (musing over the frayed ends of a broken guy wire, to the ringing echoes of "Timber!"): The complete expression for the oscillating lift force as a function of the motion cannot be formulated at the present time.

Let us press on, with cries of "Remember the Puss Moth!"

Aeroelasticity Session: (l to r) Mr. W. Targoff, Mr. B. J. Kaganov (Chairman), Mr. J. McKillop, Prof. A. A. Boorne and Mr. R. P. White

Afternoon Sessions, October 7th
(Two Sessions running concurrently)

PROPULSION

Reported by B. Quan

The Session was chaired by Mr. R. M. Sachs, Chief Design Analysis Engineer, Orenda Engines Ltd. About 100 members and guests were in attendance.

The first paper, entitled "Design and Applications of Mach 4 Turbine Engines", was presented by Mr. R. E. Neitzel, Critical Problems Engineer, Flight Propulsion Lab. Dept., General Electric Co.

He stated that several Mach 2 engines are now operational, Mach 3 engines are in development to power the next generation of air-breathing vehicles and the next logical step is to consider engines for Mach 4 flight. The relation between mission and engine performance was considered by plotting the various parameters involved. A Mach 4 turbojet was described next. This engine consists of a conventional multi-stage axial compressor driven by a single-stage turbine. The engine is run at constant speed with thrust variations being obtained by varying afterburner temperatures. Of the major engine components, only the compressor operates in an environment more severe than that of current engines. The compressor inlet temperature is estimated to be 1,130°R.

The ramjet has better performance at Mach 4 than the straight turbojet, since the drag of the compressor and turbine is absent. However, it requires some means for acceleration up to its operating speed. A reasonable approach to a Mach 4 powerplant is to use a reheat turbojet which operates as a ramjet at cruise conditions. The resulting turbojet-ramjet engine accelerates with the turbojet operating, but air by-passes directly into the afterburner for ramjet operation at cruise.

Applications of the Mach 4 turbine engines will be for manned aircraft and as recoverable boost vehicles for missile launchings.

Mr. R. F. Wilkinson, Superintendent, Explosives Wing, Canadian Armament Research and Development Establishment, presented the second paper, "Rocket Research in Canada".

He discussed the factors influencing the Canadian rocket research programme. The Canadian Armed Services carry out a primarily defensive role and the larger strategic offensive systems are not of direct interest. The position of the rocket in propulsion in relation to the pulse jet, ramjet and turbojet was indicated. Canada has decided to sacrifice the high specific impulse of the liquid rockets for the advantages of solid rockets, namely, lower cost, short preparation times, and simpler logistics.

Propulsion Session: (l to r) Mr. R. E. Neitzel, Mr. R. M. Sachs (Chairman), Mr. M. J. Saari and Mr. R. F. Wilkinson

A research programme is being conducted on case-bonded elastomeric propellants based on ammonium perchlorate and polymerizable fuel binder. Three rocket engines are being used; the largest one, which is 17 inches in diameter, will propel a test vehicle 24 ft long.

The advanced propulsion systems – nuclear rockets, free radicals, solar rockets, ion propulsion and photon propulsion – were described briefly.

Mr. M. J. Saari, Aeronautical Research Scientist, Propulsion Systems Div., Lewis Flight Propulsion Lab., NACA, presented the final paper of the afternoon – "Powerplant Design Considerations for VTOL Jet Transports".

Mr. Saari discussed the assigned virtues of VTOL transport aircraft and pointed out that the VTOL transport is a different mode of transportation and, as such, should not be considered competitive or compared directly with conventional transport aircraft. The existing and proposed VTOL configurations were described. The transport selected for analysis was the high subsonic hoverjet utilizing separate engines for hovering and cruise flight. The specifications are as follows: gross weight – 50,000 lb, fuselage fineness ratio – 10, wing loading – 150 lb/ft², wing aspect ratio – 6, wing sweep – 35°, cruise lift/drag ratio – 15, cruise speed – Mach 0.9 at 30,000 ft. The equivalent conventional jet transport considered had the same basic characteristics except that wing loading was 100 lb/ft². By considering a specific airplane and flight plan, it was established that to maximize VTOL jet transport range-payload performance it should have minimum overall thrust to gross weight ratio, minimum hover time, and minimum lift engine specific weight. The characteristics found desirable for the lift engine were incorporated in a proposal for a powerplant.

Aircraft control and powerplant layout were not considered in this paper. A spirited discussion followed Mr. Saari's paper.

Mr. Sachs closed the session by thanking the speakers and the audience.

ENVIRONMENTAL TESTING

Reported by W/C D. A. MacLulich

The Session, under the chairmanship of Group Captain R. M. Aldwinckle of the RCAF, attracted a large and interested audience.

Mr. C. A. Mills of Canadian Westinghouse Company Ltd. discussed the meaning and value of environmental simulation. After describing how single aspects of environment are tested in isolation, the combined testing of several aspects at one time was discussed. Realistic mission simulation, although difficult and costly, may yet be worthwhile in testing complete equipment compared with the costs of flight testing.

The "ENVANAL" program of the US Army Ordnance Corps was described by Mr. H. M. Bunch of the Southwest Research Institute, which assisted in developing the program. Data sheets for each complete piece of equipment record, for instance, a vehicle with its associated carried and support items, the degree of conformance to specification. Vertical columns are used for environmental factors and the crossing horizontal lines for mission or type of test. Performance is indicated by numbers – from 1 for satisfactory to 5 for totally unsatisfactory. An attempt is made to indicate the reliability or accuracy of information. The sheets are used by both the designers and the users; the latter are assisted in choosing equipment suitable to a given mission.

"Operational Value of Test Specifications" was the title of a provocative paper by Mr. E. B. Moss of Canadian Applied Research Ltd. After noting that

Environmental Testing Session: (l to r) Mr. C. A. Mills, Mr. H. M. Bunch, G/C R. M. Aldwinckle (Chairman), and Mr. E. B. Moss

military specifications are used to a considerable extent by civil aircraft operators, Mr. Moss went on to discuss and question whether this was wise and justified. There is no doubt that military test specifications as now drawn up can ensure quality. What appears doubtful is how much expensive over-insurance results from the use of military specifications in a highly competitive business. He pointed out that intangible factors, such as the standard of manufacture and the status of the manufacturing company, contribute to safety and to ensuring the required operational performance.

These questions aroused lively and interesting discussion with a dozen questions asked, some of which will be reviewed here in the form of answers only.

Wind chill gives rise to concentrated local stresses and material failures. It is difficult and expensive to simulate and is rarely done.

Testing to simulate flight is done, Mr. Mills said, on the assumption that accentuated conditions frequently applied will cause failure sooner than in flight but at the points that would eventually fail in flight. Reproducing an actual recording of flight conditions in the test laboratory is realistic if well done, but may take too long to develop a failure. However, testing specifications are continually revised or specially amended to come closer to critical actual occurrences. Conditions, vibration in particular, may be as specified at a point on a device but other parts of the equipment may be subjected to much greater or lesser values.

In answer to questions, Mr. Bunch emphasized that the ENVANAL program cannot predict minimum temperature for operation but only assures that the equipment meets a specified temperature. Ratings are revised as required. ENVANAL submits cards on complete vehicles only, not separately on components of the system.

The US Army Ordnance Corps has test facilities at Fort Churchill, Alaska, Yuma and Panama. Environments that these bases will not simulate are those of northern Greenland, Antarctica, a temperature over 115°F and high winds. The last one is covered at a test facility at Detroit where extremely high winds are simulated.

The validity of environment testing was questioned and discussed from several viewpoints. Mr. Mills claimed that a pretty good correlation has been demonstrated between failure rate airborne and failure rate in the laboratory. Mr. Bunch stated that correlation had been noted in the ENVANAL program between field and lab in some respects, such as dust and hot temperature. A pitfall occasionally encountered is when equipment designed for a certain application is used for a different application and fails prematurely as a result. One must realize that tests are made by skilled personnel and an unknown degree of service degradation is bound to occur.

The interest in this subject is a sign of maturity in industry and in the Canadian aeronautical engineering profession. The subject is basic to success although it is of less general appeal than such subjects as design and operational performance.

Aircraft Actuating Systems Session: (l to r) Mr. H. C. Zachmann, Mr. D. Royston, Mr. D. R. Taylor (Chairman), and Mr. J. A. Osterman

Morning Sessions, October 8th
(Two Sessions running concurrently)

AIRCRAFT ACTUATING SYSTEMS

Reported by E. S. R. Boughton

The Session was opened by the Chairman, Mr. D. R. Taylor, Director, Engineering Products Division, Aviation Electric Ltd., who introduced Mr. J. A. Osterman, Group Engineer, Advanced Systems Research, Georgia Division, Lockheed Aircraft Corp., whose paper was titled "Pneumatic Actuating Systems for 1,000°F Operation".

Mr. Osterman stated that because of the trend toward higher temperatures, it was only logical that interest would be directed toward a solution of the problem with a system whose service fluid is compatible with high temperatures, namely pneumatics.

Beginning in the early part of 1956, the Georgia Division of Lockheed, under contract with the United States Air Force, tackled the problem of high temperature pneumatics. The speaker pointed out that two basic points of philosophy were germane to the program right from the beginning, namely design for pneumatics, and use of the best materials, finish and surface treatments available.

Once the program philosophy had been established, the study began with a comparison of various gases – air, ammonia, argon, carbon dioxide, carbon monoxide, freon, helium, hydrogen, neon, nitrogen, oxygen, steam and sulphur dioxide. As a result, no one gas was found to be ideal; however, the greatest favour fell to air.

The speaker then went on to review the test program, highlighting actuator and rod-end bearings and those materials which were tested. Most parts of the actuator were Inconel-X while piston seals tested were of two types – the conventional piston rings and a pack of segmented carbon base rings; of all seals tested, the Boeing ring-spring seal shows the most promise.

System testing was accomplished in two phases, stability and endurance, with system endurance testing being accomplished at elevated temperatures in order of 1,000°F ambient.

In conclusion, Mr. Osterman stated that pneumatic systems can be made to operate stably. Each system must be carefully designed, recognizing the limitations which air imposes when used as the service fluid. Sealing of the piston remains one of the problem areas.

In summing up, the speaker felt that

this program has not only demonstrated the feasibility of pneumatics, but has pointed the way to a successful solution of the high temperature problem in aircraft actuating systems.

The second paper of this session was delivered by Mr. D. Royston, Senior Systems Engineer, Engineering Division, Avro Aircraft Ltd., and was entitled "Design of Hydraulic Systems for High Speed Aircraft".

The speaker began by saying that numerous articles have been written praising the relative merits of hydraulics, pneumatics and electrics for powering actuating systems, although a final decision on which system is the best can only be determined after a careful study has been made of the system requirements. In some cases, the fundamental requirements dictate the use of a particular type of power supply; in others a more detailed analysis is necessary, based on comparative weight complexity, reliability, safety, performance, and cost of hydraulics, pneumatics or electrics before the final choice is made.

This paper was primarily an account of the requirements for the design of an hydraulic system for a supersonic, two-place, twin engine, all-weather interceptor aircraft.

Mr. Royston explained that the supersonic role of the aircraft dictates the need for fully powered irreversible flight controls. When the aircraft requirements were known, the ground rules pointed to two separate hydraulic systems — one for flight controls only, capable of supplying full power and full rate to the control surfaces; the second for supplying the utility services, and also being kept as the standby system for the flight controls.

The speaker pointed out that of prime importance is the necessity of ensuring the maximum reliability of the flight control system. Therefore, duplicated hydraulic power supply is an absolute necessity and the demand for high control response rates makes an automatic switching device a requirement.

In concluding his paper Mr. Royston pointed out that high temperature hydraulic systems (550°F and above) for aircraft present many problems as to the effect on pump life and operation; dynamic and static seals for high temperature operation which present low temperature sealing problems; and the decrease in the bulk modulus of hydraulic fluids.

The third paper was presented by Mr. H. C. Zachmann, Staff Engineer, Electronics and Electrical Dept., The Martin Co., and was entitled "The Role of Electrical Actuating Systems in Supplementing Sea Master Flight Controls".

Mr. Zachmann began by discussing the primary Sea Master flight control system. He pointed out that due to the wide performance range of the aircraft, requirements dictated that the control surfaces be fully powered and irreversible. Since this type of powered systems does away with feed back of aerodynamic forces to the pilot, it was necessary to generate feed back forces artificially. This was introduced into the Sea Master by the addition of electro-mechanical actuators in the three major flight control systems for control surface positions and airplane "q".

The speaker then, with the help of slides, went on to discuss in detail the mechanics of the role of the electrical actuators in the Sea Master flight controls. As the power actuating motivation is performed by various hydraulic systems, a brief discussion of the various independent systems and their function was given.

Mr. Zachmann highlighted some of the problems that were encountered, such as inadvertent electrical runaway problems in the case of plus faults to one actuator, and how the acme screw automatically solved this problem.

Following delivery of this paper, questions were asked from the floor regarding the complexity of this type of system, particularly in maintenance and check-out time. Mr. Zachmann agreed that the system was complex but noted that check-out time was being reduced by Martin with the help of computers during pre-flight check.

MATERIALS SESSION

Reported by A. J. Bowker

It is suspected that a long evening preceding this Session accounted for the sparse attendance as this Session started. However, by the time the second paper was under way, it was noticed that the seats were well filled with an attentive audience.

The Session, under the chairmanship of Mr. R. Smallman-Tew, had an interesting selection of papers; close tolerance forgings (techniques), ceramic coatings (new materials) and ultra-high strength steels (old materials) formed the substance of the lectures.

Mr. Smallman-Tew introduced, with a minimum of vital statistics, Mr. W. Morgan of Canadian Steel Improvement Ltd. who spoke on "Close Tolerance and Other Special Forgings".

The versatility of forging processes was emphasized and forgeability of several materials was discussed. Possibly, the talk could be summarized by some statement as: "If enough care is taken in selection of materials, forms and tolerances, and if enough pieces of a type are required, closed die forgings can produce (with reasonable consistency) fairly well-finished, complicated form". The paper mentions the use of beryllium in forgings with no reference to the extreme toxicity of the dust. It should not have been left to a discussion period to bring out such a point when mentioning a relatively new engineering material.

Mr. A. V. Levy, the second speaker of this Session was introduced by the chairman to talk on the work Marquardt Aircraft Co. is doing on "Thermal In-

Materials Session: (l to r) Mr. W. Morgan, Mr. R. Smallman-Tew (Chairman), Mr. A. V. Levy and Dr. W. B. F. Mackay

sulation Ceramic Coatings". The speaker held his audience fascinated with ideas of operating engines with temperatures of up to 4,000°F, and gave some of the characteristics and application techniques of the ceramics capable of providing this performance by insulating the structural materials from the hot gases. After such a paper, one can look forward eagerly to hearing of the results his Company gets while experimenting with plasma jet spray techniques in the 4,000-6,000°F temperature range.

In the ensuing discussion the following additional information was extracted from the speaker: a crazed appearance is appreciated as an indication of stress relief; silicon carbide grit blasting is by far the best surface preparation; flamespray nichrome makes an excellent base for the ceramics; and the ceramics take abrasive wear quite well.

Finally, Mr. Smallman-Tew introduced Mr. W. B. F. Mackay, R&D Engineering with Atlas Steels Ltd., who gave a much needed reminder that, in these days of super alloys and exotic ingredients, some of those age-old preparations called "steels" have an excellent role to play. As Mr. Levy said in thanks afterwards, ". . . a most excellent, unbiased lecture . . ." and the audience agreed. Pointed out was an interesting thought that short-life performance of "structural" steels might be more often considered in short duration, high performance uses. Mentioned also were some startling results on low temperature performance of hot-worked alloys and possible trends for future metallurgical work – chiefly aiming at better high temperature performance.

Afternoon Session, October 8th

TEST FLYING

Reported by LCDR R. O. de Nevers

The final Session of the Joint CAI/IAS Meeting was chaired by Mr. E. L. Bunnell, Chief Test Pilot, Bristol Aircraft (Western) Ltd., and was devoted to Test Flying. The gallant knights who entered the lists to joust with those twin foes of post-prandial-somnolence and conference-final-afternoon static-fatigue were Mr. W. J. Potocki, Experimental Test Pilot, Avro Aircraft Ltd., and Mr. J. Walker, Chief Test Pilot, High Speed Flight Station, NASA. Weapons chosen were, respectively, "Broad Outline of Aircraft Feel: Pilot's Appreciation" and "Piloting Research Aircraft".

Mr. Potocki took up the "gage" and gamely engaged the foe. The aim of the paper was to "consolidate from the pilot's point of view the principles underlying the understanding of aircraft feel". It is believed that the aim was achieved successfully.

Test Flying Session: (l to r) Mr. J. Walker, Mr. E. L. Bunnell (Chairman), and Mr. W. J. Potocki

After a brief introduction and a short discussion of the variations of performance in that servo-mechanism known as the "human pilot", the speaker defined "aircraft feel". In part, the definition was " . . . the quality of the functional link between the man and his machine".

The development from manual to power operation of controls was described under the headings of "Steady state responses" and "Transient responses". Supersonics were discussed briefly, pointing out some of the differences between control problems in subsonic and supersonic regimes.

"Power controls (hydraulic)" were expounded more fully. The "characteristics of the various elements of power control system as related to feel" are associated with the "five major components inserted between the pilot and a control surface", i.e. "control, feel unit, linkage (including gearing), value and the jack with follow-up linkage". In assessing a particular aircraft feel, the pilot is required to investigate features common to all power control systems which affect feel quality, e.g. break-out force, back-lash etc. Each of these terms was defined and discussed leading to "some types of feel systems and their main characteristics". The "linear gear" was discussed under "pure spring feel", "Q feel" and "V feel". The "non-linear gear" was illustrated by slides and examples of installations quoted, i.e. the F-100C, F-100A and F-86E. The disadvantages inherent in the use of the non-linear gear were mentioned. In discussing the variable gear, the speaker was able to draw on his own experience of this system in a power operated transonic delta. "Synthetic feel" was shown in a block diagram and explained in some detail.

Finally, the future trend is toward a "complete severance of direct tie-up between the pilot and the control surface". Probably exchangeable package units containing feel, power and electronic elements, which could be tested on the ground prior to embodiment in aircraft, will be the solution obtained by advances in engineering design.

From a vantage point below the CAI banner and above that of the IAS, the "battle" was ably resumed by Mr. Walker. After a brief introduction, including comments on retention of the pilot in research vehicles, the speaker cited some examples of control problems experienced in flying advanced research and production aircraft at the NASA High Speed Flight Station. "These problems were not solved by eliminating any piloting function or responsibility." Solution was to be found in improved design, better airborne and ground aids, and improved methods of flight testing, retaining the pilot as an integral part of the control system". The speaker defined the responsibility of the High Speed Flight Station, i.e. "operating of special research aircraft which are designed and constructed to obtain flight data of an advanced nature". Each vehicle was built for as high performance as permitted by the state of the art and for specific research objectives. This point was well illustrated with a slide

of the X-1, D-558-II, X-3 and X-5, stating for which research areas each was designed.

The supporting "tools" used by research flight testing include internal recording measurements, verbal radio transmission and telemetering. Use of these aids greatly reduces the flight testing time and manoeuvres required to obtain "an accurate picture of the airplane derivatives and characteristics if the aircraft is stable over its entire usable flight envelope". The problem of "decrease of longitudinal control effectiveness approaching the transonic speed and simultaneous apparent increase in longitudinal stability" was illustrated with a slide of stick force plotted against Mach number. One curve on the slide showed elevator control, the other two represented all-movable stabilizer control. The procedure of working up to points of difficulty by gradual steps, with accompanying groundwork before the next flight, was outlined.

Pitching-moment plotted against angle of attack was the subject of the next slide. Stable and unstable airplane characteristics were shown. A similar process of step-by-step flight test was used here to obtain the required data.

The next slide showed a problem of more dynamic characteristics, i.e. an example of the inertia-coupling problem. The differences in the two rolls shown were readily apparent on the slide. Since the foregoing may exceed the pilot's control capability, this leads to "one of the modern giant steps in the evaluation of flight testing", i.e. the ground-based simulator and associated computers. Problems are "flown" to determine areas of possible difficulty and flight obtained derivatives are put into the ground simulator and flown "before approaching these areas in actual flight". Close correlation is obtained between ground-computed predicted data and that obtained in flight.

The use of this test technique was illustrated by a slide on directional stability at high speeds.

"One of the primary problems of the future will be that of landing." The discussion and a slide on landing at an L/D of 3 amply proved this statement. The difficulties of a glide landing were pointed out and a remedy – provide thrust for landing – was suggested. The human centrifuge at NADC, Johnsville, Fla., and improvements in pilot instrument presentation were mentioned in the final stage of the encounter. The conclusion "that piloted flight testing should be capable of assuring achievement of desired goals in the future" appeared to have been substantiated by the text.

The Session concluded with a few remarks by the President who thanked the members of the IAS and the speakers for participating in the Meeting.

(*All photos by Dominion Wide.*)

Copies of preprints presented at the Joint IAS/CAI Meeting may be procured from

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APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Position Required

Box 106 **Executive:** Engineer with honours MASc wishes to improve present position. Experienced and held several responsible positions in engineering management. Excellent references for position in sales engineering, engineering management or production. Age 35. Present salary $10,000. Challenging position and chance of future advancement more important than starting salary.

Positions Vacant

Mechanical or Aeronautical Engineer: A vacancy exists for a graduate mechanical or aeronautical engineer to assist in analysis and investigation on aero engines returned from service. Practical experience in aero engine overhaul shops would be advantageous. Under 30 years of age. Salary subject to negotiation. Apply in writing, giving full particulars of education and experience to Personnel Department, Bristol Aero Engines Ltd., Pie IX Blvd., Montreal North 12, P.Q.

Electrical Engineer: A vacancy exists in the Engineering Office for an Electrical Engineer who should be a graduate of a recognized university and have had at least two years' experience of electrical installation design in military and civil aircraft. Medical and hospitalization benefits. Pension plan after qualifying period. Write giving full details of education, qualifications and experience to the Manager, Industrial Relations Department, Northwest Industries Ltd., Box 517, Edmonton, Alta.

BRANCHES

NEWS

Cold Lake

Reported by WO J. W. Day

September Meeting

The first meeting of the Cold Lake Branch was held in the CEPE Armament Bldg. on September 16th. Mr. W. Moulenhouer, Mr. J. Partch and Mr. B. Hale from Ryan Aeronautical Co. of San Diego, Calif., gave a most interesting talk on the history, present state of the art and future developments of Drone Target Aircraft. A film was also shown.

The Chairman, F/L L. S. Lumsdaine, opened the meeting with a brief review of the objects of the CAI before introducing the guest speakers.

The subject of drone targets was particularly well received as the CEPE/AAE Detachment is being trained at present in the use of Ryan Firebee Drones, to be operated at Cold Lake. A lively discussion period followed by refreshments terminated a successful evening. Approximately 52 members and guests attended.

S/L W. J. Buchan, Programmme Chairman, thanked the speakers and outlined the programme plans for the season.

Guests are invited to the next meeting on October 19th when F/O Nicolson will talk on Helicopter Operations in the North. Films will also be shown. F/O Nicolson is one of Canada's more experienced helicopter pilots, having contributed extensively to the Mid-Canada operations.

Toronto

Reported by E. J. Lynch

September Meeting

The meeting was held in the De Havilland Cafeteria on the 23rd September, and there were 64 members and 88 guests present. Mr. J. W. Ames introduced the speakers for the evening, Mr. G. L. Oates and Mr. C. Yeates, who were members of the Canadian team competing in the 1958 International Gliding Competitions held in Leszno, Poland. The title of their talk was "A Report on the World Gliding Championships".

Mr. Yeates spoke first, dealing with the organization of the Canadian team and the organization of the competitions as Leszno. He described many of the more interesting events and reported upon the competition results.

Mr. Oates' address followed and was directed to the more technical aspects of glider design and flying, as evidenced at the 1958 competitions. He referred to the highly specialized designs which have evolved in recent years, and to the "standard" designs which have been produced to fall within the requirements of a restricted specification, aimed at encouraging the production of smaller and more easily handled machines suitable for general club use. Of 62 machines entered, 24 were in the "standard" class and, if the two classes had been in direct competition, seven of the standard machines would have been among the twenty highest scores. A description was given of the instruments developed for competition flying. Dependence upon instruments was particularly necessitated by the fact that almost all flying in the 1958 competitions had to be performed with thermal and cloud lift, rather than extensively by means of wave or ridge soaring, as had been the case in 1956, at St. Yan, France.

Mr. Oates' lecture was illustrated by 35 mm colour slides. It is to be published in the near future in *Free Flight*, the journal of the Soaring Association of Canada.

October Meeting

The meeting was held on the 15th October and took the form of a field trip, for members only, to Canadian Applied Research Ltd. Mr. D. Dalzell, C.A.R.L. Commercial Sales Manager, had arranged an excellent organization for this occasion. Small parties of members were conducted around the three plants constituting the C.A.R.L. facility, and a bus service was provided for inter-plant transportation. Senior personnel in each department were on hand to describe the facilities of the various shop departments and the environmental test laboratory, and to demonstrate and explain such interesting products as the Airborne Profile Recorder and the R-Θ Navigation System.

Upon completion of the tour, some very excellent refreshments were laid on in the plant cafeteria and Mr. E. B. Moss, Director of Manufacturing and Engineering, took the opportunity to welcome the CAI visitors to the plant. Mr. W. H. Jackson, Chairman of the Branch, called for a vote of thanks and the meeting was terminated without any further business. As nearly as could be determined, there were 107 members in attendance.

At Cold Lake: (l to r) Mr. W. Sved, Mr. W. Moulenhouer, Mr. B. Hale, F/L L. S. Lumsdaine, Mr. E. Griffin and Mr. J. Partch

Montreal

Reported by I. S. Macdonald

October Meeting

The second regular dinner meeting of the Montreal Branch was held in the ICAO Building on the 15th October.

W/C C. R. Thompson chaired the meeting and also introduced the speaker, Mr. D. A. Buck of the Boeing Airplane Co. Mr. Lee Capreol, Manager of Montreal Airport, was a guest at head table.

Mr. Buck gave a most interesting talk on the very topical subject, Jet Sound Suppression. He supplemented his discussion with slides which gave a very clear picture of the sound suppression problem and the steps taken by Boeing to minimize the production of jet noise.

The suppressors operate on the principle of breaking up the primary jet exhaust stream into a number of small streams, promoting the quick mixing of the hot gases with the outside air and spreading the mixed gases over a large area. The quality of the exhaust noise is radically altered and the rumbling and crackling noise associated with unsuppressed jets is no longer present.

The conclusion of Mr. Buck's talk indicated that while definite steps had been made toward good sound suppression, the result is still relatively noisy when compared with current reciprocating engines.

Several questions were asked by members regarding weight and performance penalties as well as life expectancy of the units.

Fifty-two members attended the dinner and seventy-seven were present for Mr. Buck's address. The speaker was thanked by Mr. T. A. Harvie.

W/C Thompson gave some details of the planned Christmas party on December 10th and also advised that the Governor General would attend the Golden Anniversary Dinner on the 23rd February, 1959.

Calgary

Reported by H. E. Hampshire

October Meeting

This was a Dinner Meeting, held on the 15th October at the Royal Hotel and attended by 30 members and guests.

After the introduction of the members and guests at the head table, Mr. W. A. B. Saunders, Chairman, opened the meeting with a general business discussion. During this period, Mr. A. R. G. Leckie, who had recently attended the Joint IAS/CAI Meeting in Ottawa, briefed members on his visit.

The guest speaker of the evening, Mr. R. P. Hughes, Quality Control Supervisor, Trans-Canada Air Lines, was introduced by Mr. Leckie and, following his talk, was thanked by Mr. J. D. Zmurchyk.

Mr. Hughes opened his talk by circulating copies of the organization chart of TCA's overhaul base at Winnipeg and then gave a brief breakdown of how the various departments and sections coordinate and function. He then went on to explain the difference between the operation of the other departments and the Quality Control Dept. Mr. Hughes explained that the prime function of his department was the investigation of failures and inability of certain items and components to run their normal scheduled life. Emphasis was, of course, placed on safety plus the economics of rectification action found to be necessary. Mr. Hughes outlined his department's handling of various items and component parts, each of which proved a most interesting subject to listen to. He further explained the tremendous value that both the operator and the manufacturer obtained by personal contact between their representatives when conducting investigations and research into problems of mutual interest. Mr. Hughes concluded his most informative address by indicating some of the characteristics and traits essential to a man involved in this type of work.

Following a brief intermission, Mr. Saunders introduced Mr. P. Anderson of the Foundation Co. of Canada, who gave a short introductory address before showing his Company's film, "Arctic Adventure" – a most interesting account of the building of the DEW Line.

Halifax-Dartmouth

Reported by CPO A. C. Green

October Meeting

The second meeting of the current season was held in the cinema of the CPO's Mess, HMCS Shearwater, on the 16th October. A total of 26 members and guests were present.

The Vice-Chairman, Mr. R. Wallworth, informed the members that the Chairman, CPO R. L. Sabourin, could not attend the meeting. Mr. Wallworth went on to say that the intended speaker, LCDR R. Wagner, had been forced to cancel his arrangements because of unforeseen Service commitments and that a number of interesting films would be shown instead.

The blazer badge was next placed on display and members were informed of its price and how it may be obtained.

Three films dealing with aircrew survival were shown. The first one "Survival in the Summer Bush", showed the actions of the crew of a Dakota which crashed in the bush. It illustrated how to make the best of the emergency equipment, the local terrain, and ingenuity and initiative of the crew. It proved that a well-prepared crew, working together, could survive with a reasonable degree of comfort.

The next film, which was equally well produced, gave the same type of message under different conditions. "Survival in the Summer Arctic" dealt with the plight of a downed pilot, on his own, in the tundra.

The third film, which was nameless, showed a class undergoing Survival Instruction. This provided good illustrations of the preparation of a tepee, lean-to, signal fires, fishing nets and snares.

CPO R. MacDonald was on hand to answer a number of questions asked by the members and guests.

At the conclusion of the meeting, Mr. Wallworth informed the audience that the speaker for the November meeting would be LCDR R. Wagner and that the topic would be "Electronic Controlled Weapons".

SECTIONS

NEWS

Astronautics

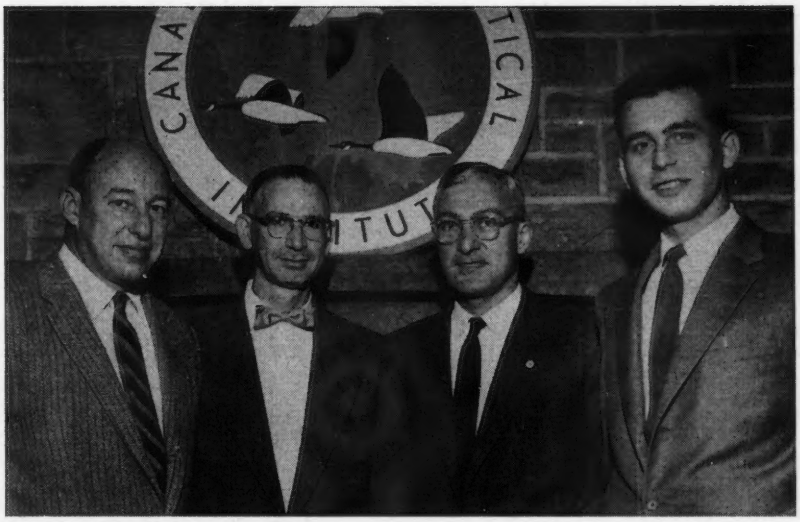
The first meeting of the Astronautics Section was held on the 9th October in the pleasant atmosphere of the RCAF Gloucester St. Mess, Ottawa, with 38 members in attendance. After an introduction by Mr. W. F. Campbell, Chairman of the Interim Committee, who gave some information on this Section (see also *Canadian Aeronautical Journal*, September, 1958, p 256), the meeting was turned over to the first Executive consisting of Dr. H. S. Ribner, Chairman, Mr. D. Bogdanoff, Vice-Chairman, Mr. J. A. van der Bliek, Secretary-Treasurer, and Mr. W. F. Campbell, Past-Chairman. Dr. Ribner took the chair and started by asking Mr. H. C. Luttman to explain the mechanism of CAI Sections. Since this Section is operating similarly to other existing CAI Sections, it seems unnecessary to go into details. The CAI has copies of Section Regulations available for anyone interested. All CAI members interested in astronautics are invited to apply for membership of this Section; forms are to be obtained from CAI Headquarters.

One question raised during discussion was the position of the Astronautics Section with regard to the two existing Canadian Astronautical Societies. The aims and activities of these two societies appear to be different from those of the CAI; however, the Astronautics Section will provide a point of contact and channel for cooperation with these societies.

The main items on the programme consisted of three technical papers, a short review of which follows. These papers are scheduled for publication in the Journal.

The first paper presented was titled "The Clock Paradox" by Mr. W. F. Campbell, National Research Council.

When clock B is moved away from clock A (on earth) at a speed comparable to the speed of light, and is then returned to A, it will indicate a smaller elapsed time than A. This result follows from the special theory of relativity. The paradox enters when B is regarded as stationary and A as moving (still fixed with respect to earth). In this case, purely relative motion would indicate the opposite effect.



Executive Committee of the Astronautics Section: (l to r) Mr. D. Bogdanoff, Vice-Chairman; Dr. H. S. Ribner, Chairman; Mr. W. F. Campbell, Past-Chairman; and Mr. J. A. van der Bliek, Secretary-Treasurer

Mr. Campbell reviewed three possible solutions of this paradox and concluded that one of them is correct. The general theory of relativity has to be taken into account, introducing the effect of changing gravitational potential on time. In the case where clock B is regarded as stationary, to provide the accelerations clock A on earth will have to be subjected to a uniform gravitational field in which it falls freely; the same forces are then required to maintain B at rest. It was shown that by introducing this gravitational potential the time difference indicated by A and B is independent of which clock is regarded as stationary.

Finally experimental methods were indicated to remove the clock paradox once and for all.

The discussion included the definition of time, which was not given, but appeared irrelevant to the problem as long as time can be measured by observing physical processes.

Dr. H. S. Ribner of the University of Toronto presented the second paper entitled "Propulsion Systems for Space Travel". The speaker started by pointing out that chemical rockets, although adequate for placing satellite stations in orbit, are not suitable for space flight because of the large takeoff weight and relatively low exhaust velocity. Other things being equal, the speed gain is proportional to the jet exhaust velocity. However, the magnitude of the thrust of a space ship does not have to be excessive. As an example, a thrust to gross weight ratio of 10^{-4} was quoted for a trip to Mars in 450 days, whereby the thrust is to be maintained for many months.

Various thrust producing systems were reviewed: thermal systems, using for example solar or nuclear energy, ion propulsion systems, plasma propulsion, photon propulsion and the isotope sail. These schemes were illustrated by slides and some of their characteristics were discussed briefly.

The third and last paper was presented by Mr. D. Bogdanoff of Canadair Ltd. The paper was titled "Guidance and Control" and was in the nature of a review. The two main headings were guidance and control of missiles in the atmosphere (limited to air-to-air and ground-to-air missiles) and guidance and control of missiles travelling (partly) outside the atmosphere (ballistic missiles and satellite rockets).

In the first case the type of flight path is of primary importance, the aim of the missile being collision with a moving target, thus requiring a constantly changing path. The various types of guidance were discussed bringing out

the limitations of each of these. The control for these missiles is effected by an error signal translated into missile accelerations, caused by aerodynamic control surface deflections. Major control problems connected with airplane-like (with wings) and cruciform type configurations were discussed. It was particularly interesting to note the complex, often non-linear, set of problems – actuating devices, controls, non-linear aerodynamic transfer function, aeroelastic effects etc. – making an ideal missile almost an impossibility.

The second part of the lecture dealt with long range ballistic missiles and satellites. In this case the requirements for guidance and control are quite different. The missile can move along a pre-calculated orbit. The basic requirement for guidance is to obtain a predetermined velocity vector at a given point in space at motor cut-off. Because of fuel economy this means usually a fixed flight path. A command guidance system or pulsed radar may be used to effect correction from calculated flight path.

The guidance systems of an IRBM and an ICBM were discussed in more detail. Thrust vector control rather than aerodynamic control surfaces were used with this type of missile.

MEMBERS

NEWS

Dr. J. W. Abrams, A.F.C.A.I., has left RCAF Headquarters to go to Supreme Headquarters Allied Powers Europe to undertake important duties in the scientific analysis and planning of western European air defences.

Dr. R. H. Lowry, A.F.C.A.I., has left the RCAF and is presently employed as Manager, Space Medicine Branch, Systems Management Office, Boeing Airplane Company, Seattle.

Capt. D. D. Murphy, A.F.C.A.I., Regional Superintendent Air Regulations, Dept. of Transport, Vancouver, has been awarded the AOPA award for the integrity, spirit and leadership which he gave for promotional activities for private aviation.

W/C G. E. Bould, Technical Member, recently left New Zealand to take up a position with the Fund Raising Directors Ltd., Buckingham Gate, London, England.

G. K. Rasanen, Technical Member, has resigned his position at De Havilland Aircraft of Canada Ltd. to take up a position as Stress Engineer with Boeing Airplane Company, Seattle.

DEATHS

It was with deep regret that we learned of the deaths of the following members:

F/L E. Charters, M.C.A.I., who was Station Aeronautical Engineer, RCAF Stn. Sea Island, B.C.

N. Ring, M.C.A.I., who was killed accidentally during the National Gliding Competitions. At the time of his death he was Chief of Airframe Design, Avro Aircraft Ltd.

ADMISSIONS

At a meeting of the Admissions Committee, held on the 14th October, 1958, the following were admitted to the grades shown.

Associate Fellow

C. W. Lemmerman, President, C. W. Lemmerman, Inc., 111 Lafayette St., Hartford, Conn.

A. L. Sutton (on transfer from Member)

Member

B. R. Aubin, Engineer–Structures, Trans-Canada Air Lines, Montreal, P.Q.: *4331 Circle Rd., St. Genevieve, P.Q.*

H. N. Beffort, Production Shops Manager, Avro Aircraft Ltd., Box 4004, Terminal A, Toronto, Ont.

V. W. Bowers, Assistant Plant Manager, The Fairey Aviation Co. of Canada Ltd., Sidney, B.C.: *2777 Benson Pl., Victoria, B.C.*

V. W. Dzwala (on transfer from Technical Member)

Technical Member

A. Anderson, Jr., Technical Representative, Gilfillan Bros. Inc., Los Angeles, Calif.: *c/o Officers' Mess, RCAF Stn. Cold Lake, Grande Centre, Alta.*

F/O J. P. Cadieux (on transfer from Student)

PO M. H. Droeske, RCN, Air Technician, HMCS Shearwater, N.S.: *8 Tallahassee Ave., Clarence Park, Halifax Co., N.S.*

H. T. Dutfield (on transfer from Junior Member)

G. Eardley, Flight Service Inspector, Avro Aircraft Ltd., Malton, Ont.: *3265 Etude Dr., Malton, Ont.*

F/O D. J. H. MacCaul, RCAF, Flying Instructor, Officers' Mess, RCAF Stn. Penhold, Alta.

E. Pitoulis (on transfer from Junior Member)

M. Wojcik, Leadhand, De Havilland Aircraft of Canada Ltd., Downsview, Ont.: *473 Willard Ave., Toronto 9, Ont.*

Student

G. Bleier, McGill University, Montreal, P.Q.: *522 Sherbrooke St. W., Apt. 27, Montreal, P.Q.*

H. Chang, McGill University, Montreal, P.Q.: *3575 Shuter St., Montreal, P.Q.*

P. A. Collyns, McGill University, Montreal, P.Q.: *3434 McTavish St., Montreal, P.Q.*

M. D. French, McGill University, Montreal, P.Q.: *51 Claude Ave., Dorval, P.Q.*

D. E. Guitton, McGill University, Montreal, P.Q.: *8983 Basile Routhier St., Montreal, P.Q.*

O. Hawaleshka, McGill University, Montreal, P.Q.: *6010 - 31 Ave., Montreal 36, P.Q.*

J. S. Kuchta, McGill University, Montreal, P.Q.: *6352 - 11 Ave., Rosemont, Montreal, P.Q.*

G. E. Merritt, McGill University, Montreal, P.Q.: *70 Chesterfield Ave., Westmount, P.Q.*

C. W. Naigle, Provincial Institute of Technology and Art, Calgary, Alta.: *6732 - 23 St. S.E., Calgary, Alta.*

C. A. Potter, McGill University, Montreal, P.Q.: *3484 Durocher St., Apt. 201, Montreal, P.Q.*

G. F. White, McGill University, Montreal, P.Q.: *2277 Goyer St., Montreal, P.Q.*

Associate

J. Robulak, Station Manager, Trans-Canada Air Lines, McCall Field, Calgary, Alta.

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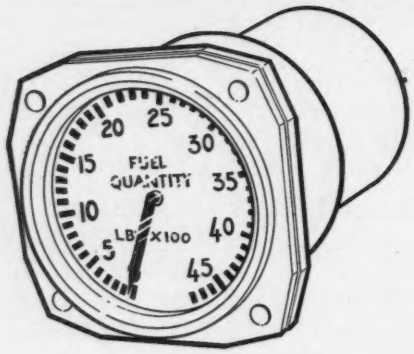

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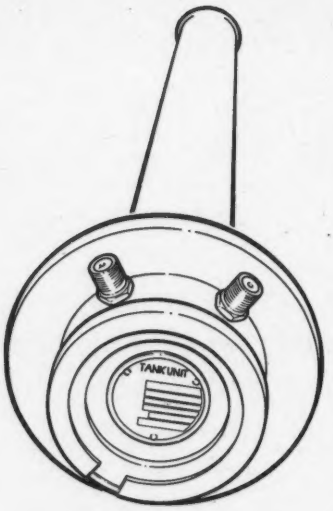

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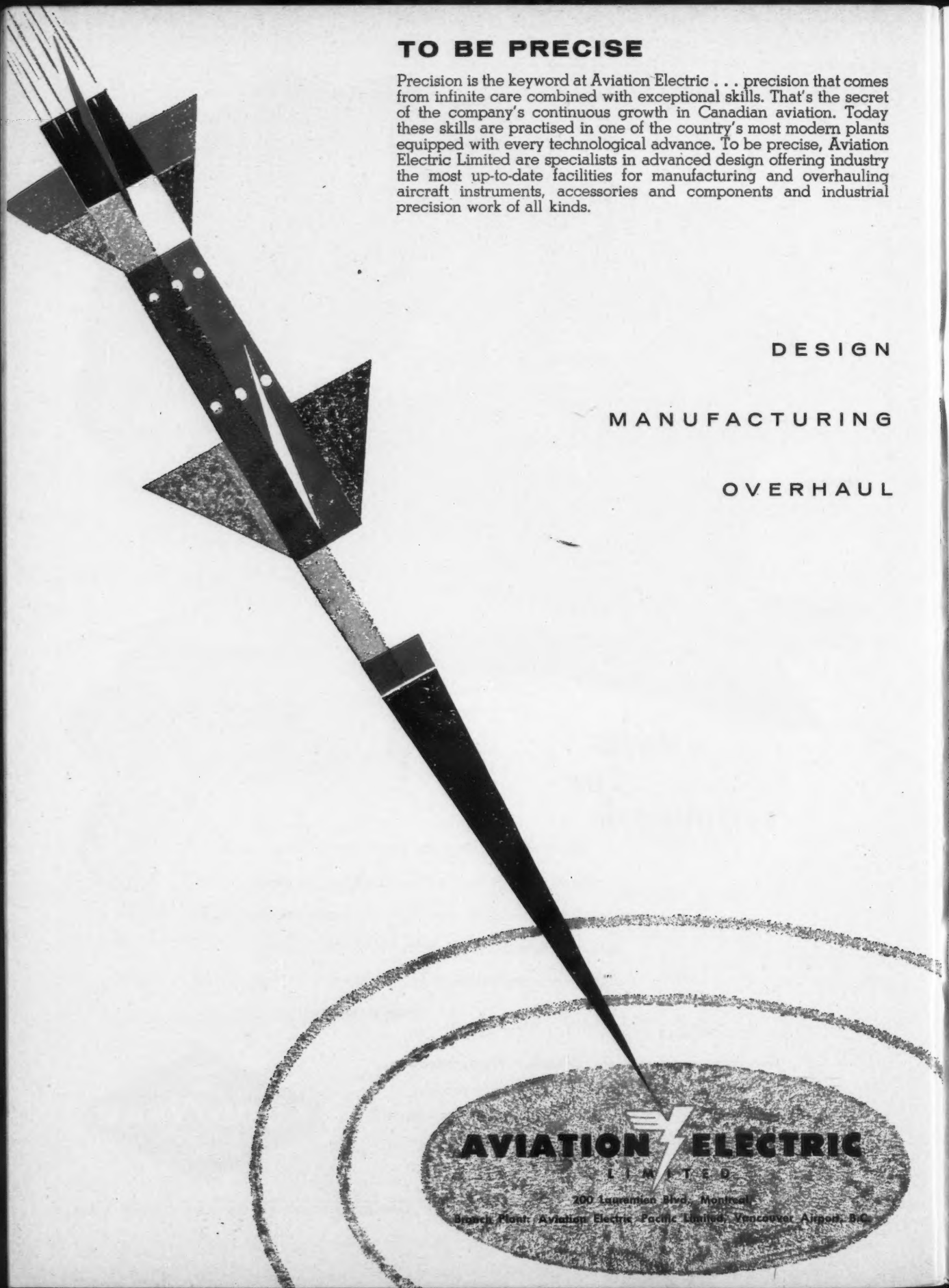

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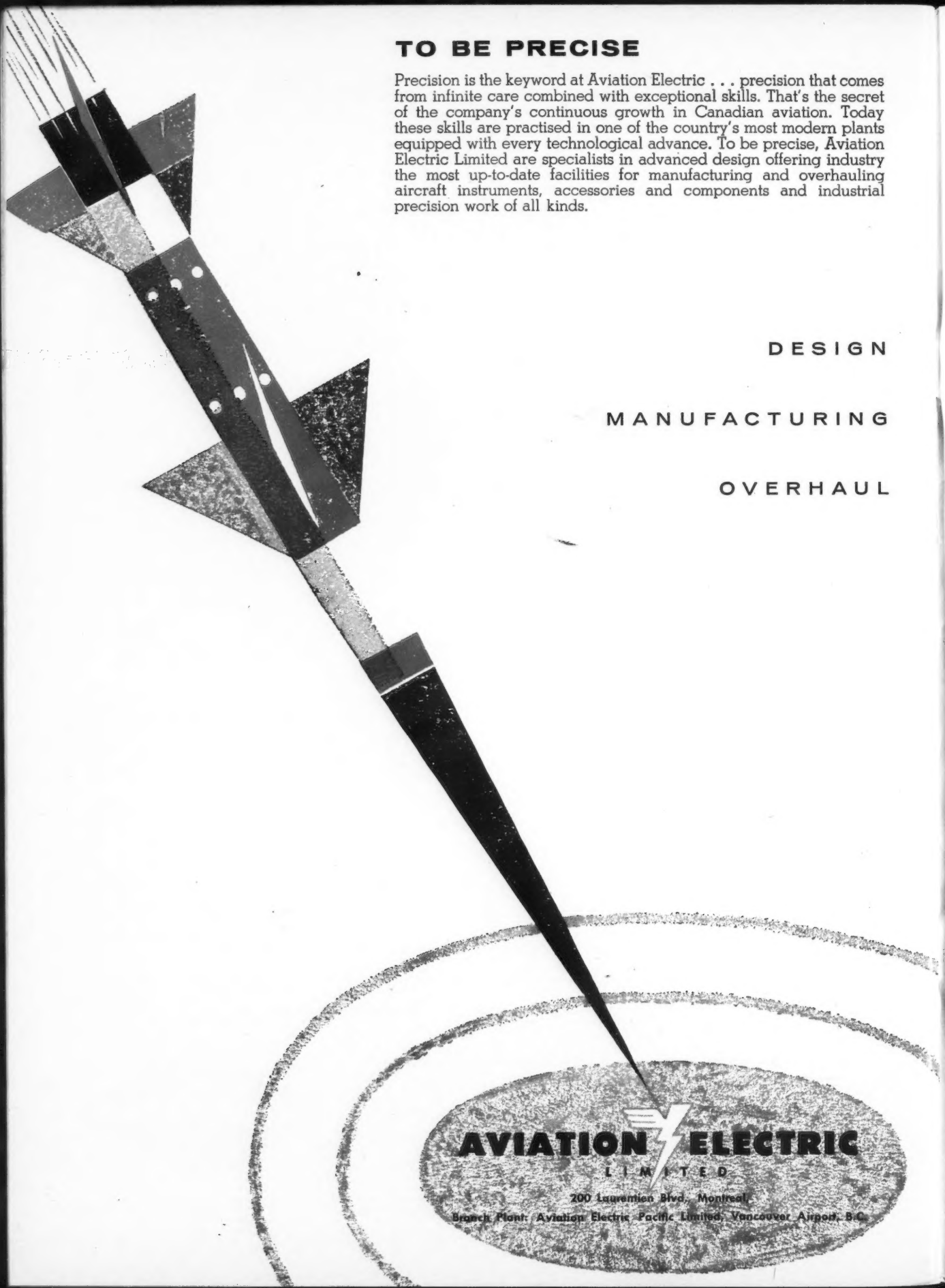

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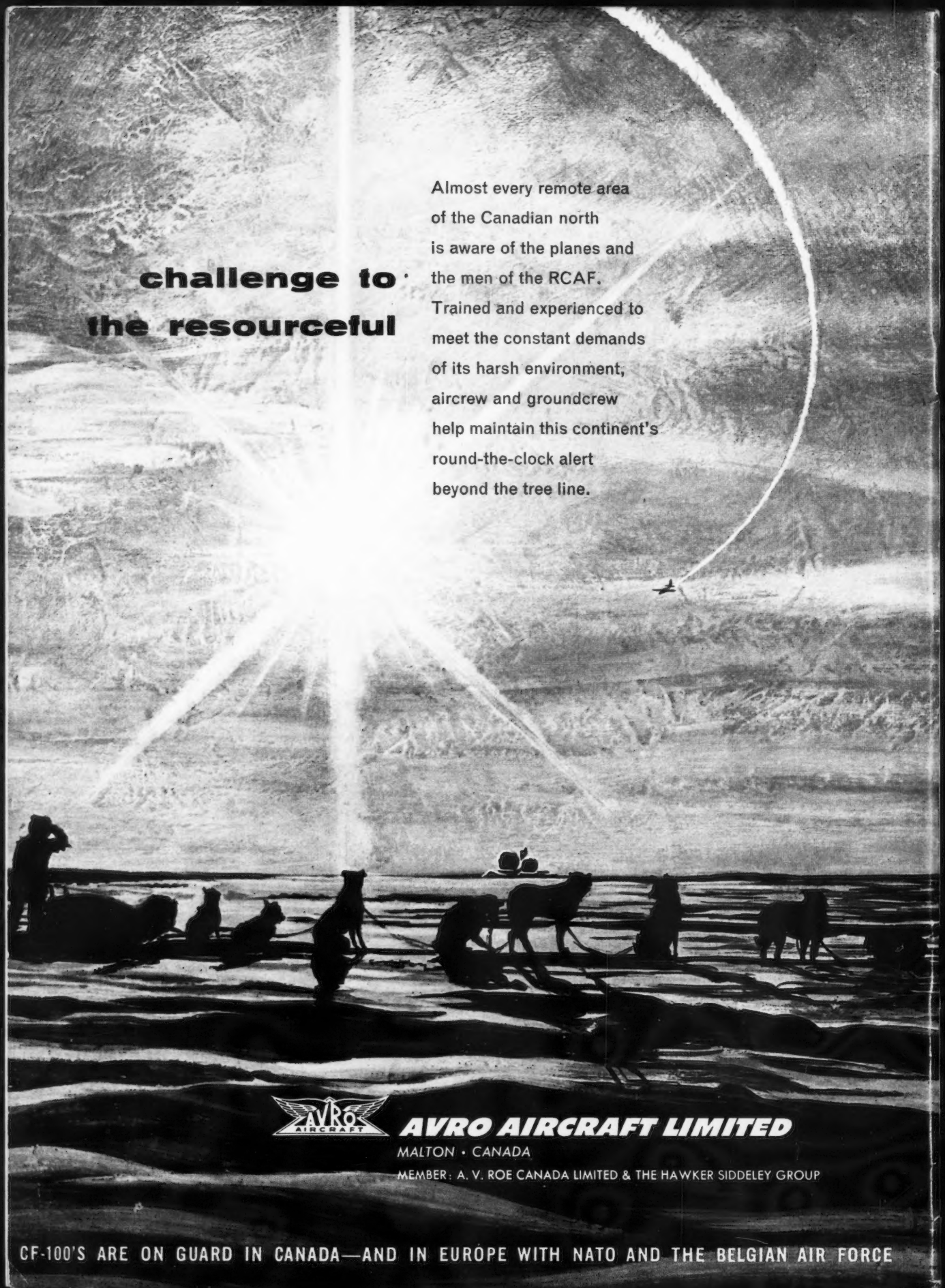
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